THE JOURNAL OF THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

APRIL 1961

Vol. 55, No. 2 Whole No. 449

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OF CANADA

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A MEDIAEVAL PORTABLE SUN-DIAL

By Frederick A. Stebbins
Longmeadow, Massachusetts

In figure 1 of this article is presented a mediaeval portable sun-dial that the reader can copy or even cut out and put to use. It is constructed for latitude 46° north, but the error is small for places within one or two degrees of that parallel. It furnishes an excellent insight into the sound mathematics of the early astronomers. Theoretically, it gives a perfectly accurate solution of the polar triangle met in problems of navigation.

To make the dial

1. Mount figure 1 on cardboard.
2. With a knife cut through the heavy line in the centre of the date scale from December 22 to June 21.
3. Also cut through the heavy lines on three sides of the small rectangle in the upper right corner. Bend the rectangle toward you, folding on the fourth side, the dotted line, so that it stands up from the card.
4. Take a coarse thread about a foot long. Pass the thread through a small bead with a hole of such size that the bead can be pushed along the thread, but, once pushed, will stay in place and not slide of its own weight.
5. Put one end of the thread through the slit in the date scale and tie it to some small object, such as a scrap of paper, so that it will not slip back again. Attach a weight to the other end of the thread.

To operate the dial

1. Move the thread so that it comes through the date scale at the date of observation.
2. Stretch the thread across the tip of the horn and slide the bead so that it rests in the circle next to twelve o'clock.

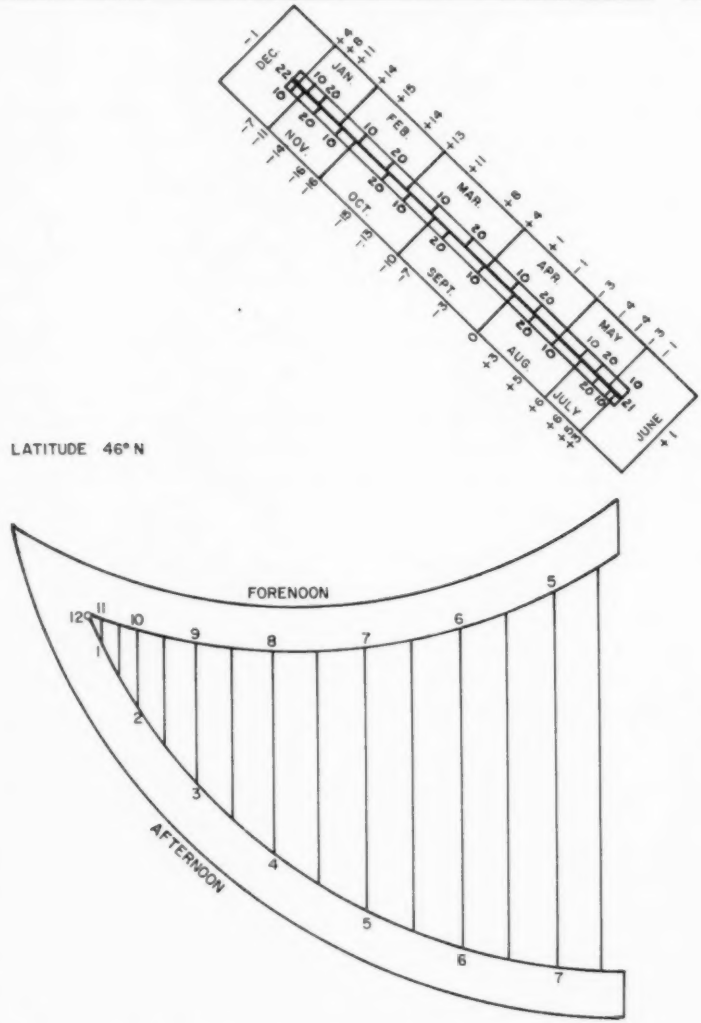

FIG. 1—Mediaeval portable sun-dial called the Capuchin.

3. Hold the card so that the surface is vertical. Turn so that the right-hand edge is directed toward the sun. Tilt the card so that the shadow of the tab in the upper right corner lies wholly between the two parallel lines across the top. The weight holds the thread perpendicular, and the bead, which should be just touching the surface of the card, indicates the time by its position among the hour lines.

Corrections

Any sun-dial, even one on a marble pillar in a rose garden, must be corrected in three ways to make it agree with modern clocks.

1. Daylight saving. If daylight saving, or summer time, is in effect, add one hour to the time given by the dial.

2. Longitude. For each degree of longitude that the observer is east of the standard meridian of his time zone, subtract four minutes of time from the reading of the dial; for each degree west, add four minutes.

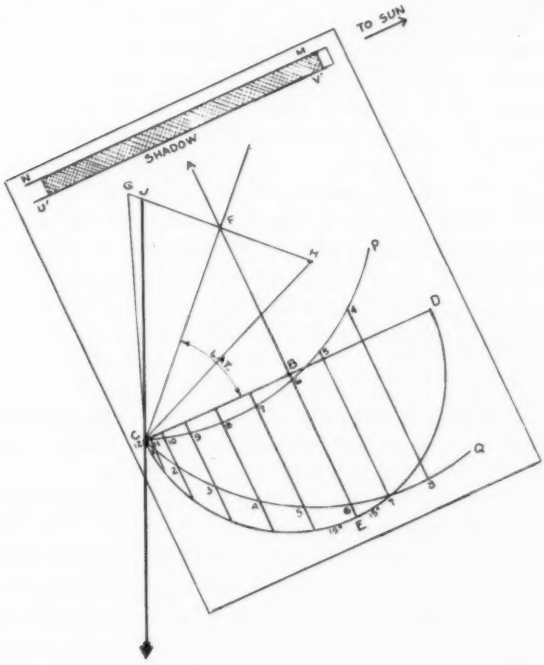

FIG. 2—Construction and operation of the Capuchin dial.

3. Equation of time. Next to each date on the scale is a figure which shows how many minutes one should add to, or subtract from, the reading of the dial on that date.

Obviously, this dial is of the classification known as altitude dials; and, as is always the case with this type, it must be adjusted for the date of observation and does not distinguish between forenoon and afternoon. It has been named the Capuchin, as the horn-shaped figure suggests a monk's cowl thrown back.

Figure 2 gives the method of laying out the dial. Draw AB perpendicular to CD at B. On centre B draw the semicircle CED. Divide this arc at 15° intervals, one for each hour. The hour lines are drawn perpendicular to CD passing through the various 15° divisions. The hours may be subdivided as desired, four minutes of time making one degree of arc. Draw FC so that angle FCD equals the observer's latitude, here 46°. F lies on AB. Draw GFH perpendicular to FC at F. Make GFH of such length that angles GCF and HCF are each equal to $23\frac{1}{2}$°. For the date scale on GFH, find in an almanac* a table of the sun's declination. A table for the second year after leap year gives the most accurate results. Locate each date so that a line drawn from that date to point C will make an angle with CF at C equal to the sun's declination for that date. Figure 2 uses as an example the date January 21 at J. On that date (and also on November 21) the sun's declination is 20° south, so angle JCF equals 20°. $V'U'$ and MN are parallel to DC. Arc CP centred on G and arc CQ on H mark the limits within which the bead will always lie.

To see how the dial works, compare figure 2 with figure 3. Figure 2 gives an example of the dial in operation at noon on January 21 or November 21, when the sun's declination is 20° south. The bead is at C. Figure 3 shows the celestial sphere, as commonly pictured in elementary books on astronomy, drawn for the same latitude, hour, and date. The sun is at C. The two figures have the same lettering. To lapse a moment into technical language, this dial is an orthographic projection of the celestial sphere reduced to convenient scale, and made on the plane of the azimuth circle where the sun is located at the time observation. Figures 2 and 3 will be found in substance identical. In figure 2 the centre of the celestial sphere is the point where the thread is suspended, and its circumference is the arc made by the bead as it scrapes over the surface of the card. The rays of sunlight lie parallel to the prime vertical, UV in figure 3, while the thread lies over the line from the centre of the sphere to the sun.

*The Observer's Handbook, p. 7, gives this information for 3-day intervals—Editor.

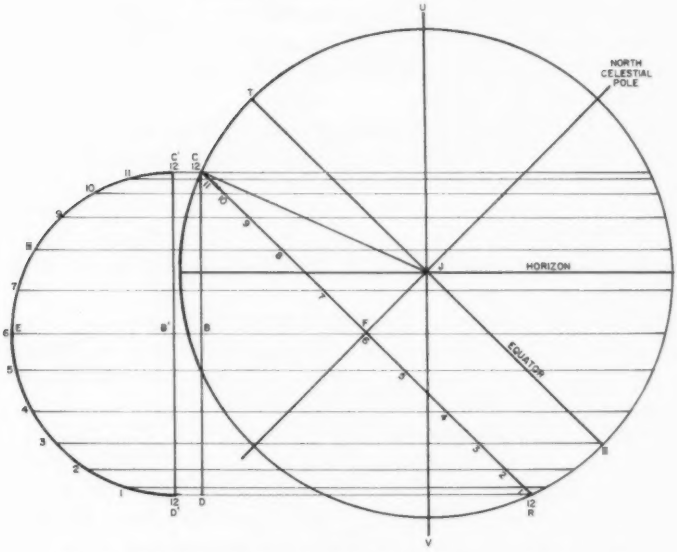

FIG. 3—Projection of the celestial sphere. Compare with figure 2.

Consider figure 3. From midnight to noon the sphere turned so that the sun travelled along its path, *RFC*, a circle seen edgewise. The numerals show its position for each hour. The sphere turns 15° an hour, so the numbers are 15° apart. The parallel lines are the edges of circles of equal altitude drawn through the hour divisions. A familiar proposition of geometry states, "If parallel lines intercept proportionate parts on one transversal, they intercept proportionate parts on any transversal." Therefore, these parallels divide *DBC* in the same proportion as *RFC*. *DBC* can be considered a circle seen edgewise, smaller than *RFC*, or it may be considered the diameter of *C'ED'*, the semicircle used to lay out the dial.

If the reader wishes it, he will find a trigonometric proof in the article "Dial" in the eleventh edition of the *Encyclopaedia Britannica*. This, by several steps, works out a trigonometric formula to express what the dial does, and then shows that it is the identical formula used to find the hour angle in the polar or "*ZPS*" triangle of navigation. This proves that the solution is correct, but does not help to visualize the construction. Later editions of the *Britannica* condense the article and omit this proof. Instead they include a picture of this type of dial worked into a picture

of a monk with the hour lines on his cowl. There is another more lengthy mathematical treatment, also with formulae, by A. W. Fuller in the *Mathematical Gazette* for February 1957. This concurs that the dial gives a correct result.

The function of the sliding bead is curious. Suppose the date is the equinox. Then the sun's path lies along *SJT* in figure 3. *SJT* is longer than *RFC*, but the hour divisions, while larger, are in the same proportion. Here is where the inventor showed his ingenuity. The dial uses the same hour lines for all dates and redraws the rest of the projection to a scale to fit the hour lines. The position of the sliding bead gives the length of the radius of the sphere.

If the hour should be other than noon, the sun's path would not appear as a line in the projection, but as an ellipse. This would be difficult to draw, but it is not necessary to draw it as the spacing of the hour lines is the same as for the noon position. At no time are the important lines or angles distorted by foreshortening.

The dial can be modified for use in all latitudes as a universal dial. British and European museums have many examples dated from 1500 onwards. Usually they are engraved on a brass plate about the size of a postcard. The design is shown in figure 4. The latitudes are projected onto the centre line as in figure 2. The two date scales, at right angles to each other, are usually divided into equal zodiacal signs rather than unequal months. The thread is tied to a jointed arm attached to the top. This is moved so as to bring the support to the intersection of the appropriate lines for latitude and date. The thread is then drawn to the right and the bead placed on the proper date on the second scale. There is a simple geometric proof to show that the construction in figure 4 gives the same result as that in figure 2.

This universal instrument is usually called the dial of Regiomontanus, a German astronomer, whose dates are 1436–1476. It would seem that he did no more than popularize it, because it is so clearly and closely related to the navicula (Latin for "little ship") which dates from the twelve hundreds. A picture of a navicula, though this example is of a later date, appears in figure 5. The support for the thread slides on the mast to adjust for latitude, and the mast rocks back and forth over a scale on the keel to adjust for date. Note the second date scale on the right. The sunlight is made to shine through pin holes in the turrets. See *Early Science in Oxford* by R. T. Gunther, volume II, page 375, for a reprint of a fourteenth century Latin treatise giving practical directions for making such a dial. The navicula differs from the Regiomontanus dial in that when the adjustment is made for date, the thread support moves

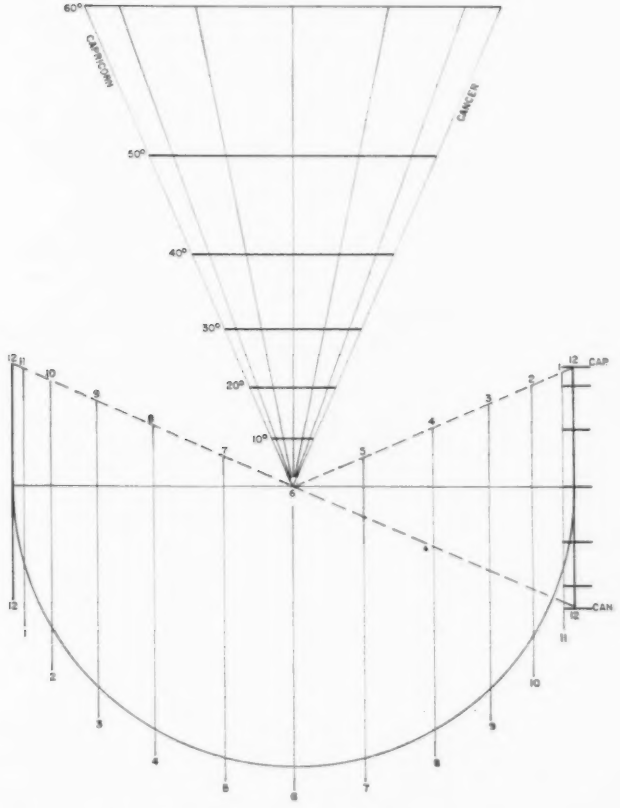

FIG. 4—The dial of Regiomontanus, the Capuchin made universal.

over a curve instead of in a straight line. Of the two constructions, it is the one in figure 4 that is correct. Some naviculas attempt to avoid this error and become overcomplicated in doing so. The error is small, usually lost in uncertainties of observation, and should not detract from the ingenuity of the construction.

As to historical origin, the oldest examples of these dials that are to be found in museums are naviculas. Nevertheless it seems a fair surmise that they were invented in this way. Some mediaeval astronomer solved his spherical triangles graphically. Noting that the hour lines were always

FIG. 5—Navicula de Venetiis, or Ship Dial. Made about 1450. Brass. Overall width 83 mm. (Courtesy of the Curator of the Museum of the History of Science, Oxford, England.)

spaced in the same proportion, he probably drew a lot of them at one time for future use. Constructing his diagrams to fit the hour lines would lead to the discovery of the Capuchin dial. An added step to make it universal would lead to the Regiomontanus type, and a simplification of the mechanical construction would lead to the navicula. This would mean that they were all known in the thirteenth century and possibly much earlier. In any case, the brass navicula, suggestive of a Spanish galleon, must remain as one of the most colourful relics of mediaeval astronomy that have come down to us.

TIDAL-ELECTRIC POWER GENERATION—II

By F. Keith Dalton

Toronto Centre

In the February 1961 issue of this JOURNAL some of the features of ocean tides and of power development were mentioned. Proposals for using the tides to generate power have two basic methods, namely, one-pool and two-pool systems.

One-Pool System. As the name implies, this system in its simple form has only one basin which is separated from the sea by a continuous dam constructed across the estuary and containing flood gates and the turbines. The basin is filled through the flood gates while the sea rises from mid-tide to maximum height and discharges through the turbines after the tide has fallen back to mid-tide level.

Several small tide mills were operated on this principle in England and other European countries in the 11th century for grinding corn and gypsum and for sawing timber. In 1734, Slade's mill in Chelsea, Mass., using four waterwheels and developing 50 horsepower, was built to grind spices. Many more tide mills were operated later along the New England coast. Waterwheels were permissible only in the most simple one-pool systems.

There are three different methods of operating one-pool installations:

1. The Simple-Emptying Scheme: Power is generated while the water passes through the turbines from the basin to the sea during the lower part of the falling-tide cycle—from mid-tide to low tide, a period of about half, at most, of a tide cycle (figure 5). The energy during the filling of the basin is lost.

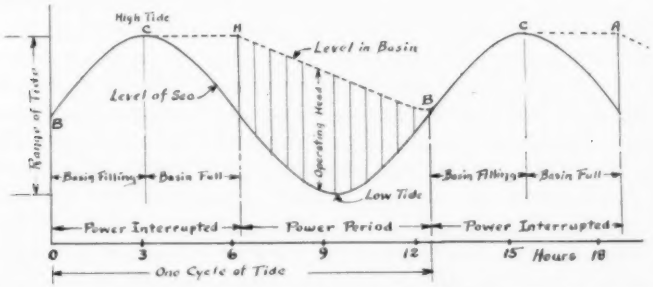

FIG. 5—One-pool system: simple emptying scheme. *A–B*: Generating power. *B–C*: Filling basin. *C–A*: Idle. Generation for 50% of tide cycle. Total interruption: *B–A*. Maximum operating head: 78% of tide range; average head, over one cycle: 28%.

2. The Double-Emptying System: Power is generated both when the water moves from the basin to the sea at low tides and when it moves from the sea to the basin at high tides.

3. The Double-Emptying Double-Pumping System: Similar to Method No. 2 but with pumping added to minimize the period of interruption of power and to use the basin at higher water levels and, therefore, with increased loads (figure 6). Total generating periods would be about 8 hours per cycle of tide.

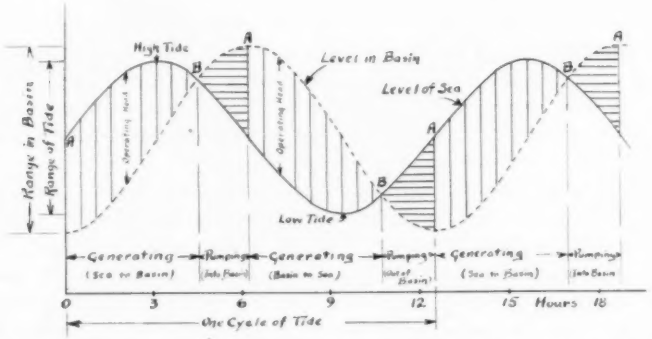

FIG. 6—One-pool system: double-emptying, double-pumping. *A–B*: Generating power. *B–A*: Pumping. Generation for 70% of tide cycle. Interruptions, two per cycle: *B–A*. Maximum operating head: 78% of tide range; average head, over cycle: 39%.

Whichever of these methods is used, however, the power output will vary considerably and daily shutdown periods can not be avoided at times when water levels on opposite sides of the dam are so nearly equal that there is not sufficient operating head for the turbines. These interruptions will occur once or twice in every cycle of the tides depending upon which of the above schemes is used.

The double-emptying scheme, without pumping, was given some consideration but does not appear to be much improvement over the simple-emptying idea; water does not enter the basin as freely when it must flow in through turbines instead of wide open flood gates. Also, valve operations would be more complicated with two interruptions of power service per tide cycle.

However, an arrangement was suggested with passages in the dam in the form of the letter "H" for each unit, valves at all ends of the letter and the powerhouse in the crossbar. It operated on the same principle as a full-wave electrical rectifier of alternating currents. Water entering the

dam from either the sea or the basin passed through the turbines in one direction only. Two valves were open—for entry and discharge—while the other two were closed. Therefore, one-way low-head turbines could be used but each unit required an appreciable length of dam construction thereby setting a limit, possibly too low a limit, to the number of units that could be accommodated in a dam of given length. The double-emptying scheme, without pumping, was not deemed practical for development.

When pumping is added to the double-emptying scheme, however, a more efficient installation can be obtained at very little additional expense. Water pumped into the basin at high tide against only a low head will give an increase in power due to the now higher total operating head than otherwise would be obtained. An increase of 35 to 40 per cent. in head over the simple emptying scheme can be realized. In this method there need be no operation of flood gates; the units would now act as both pumps and turbines.

The average operating head to be obtained in these systems, computed for a complete cycle of the tides, appears to vary directly as the range of the tide at any time and in any location being about 28 per cent. of the tide range for the simple-emptying system but 39 or 40 per cent. for the double-emptying scheme with pumping.

French Project and Proposals. The present French project on the River Rance and two proposals for very extravagant developments are all of the one-pool type, double emptying with double pumping.

River Rance Project. After many years of study and of hydraulic measurements on a scale model and on the estuary itself, construction was started on an actual development on this river which flows into the English Channel at the seaport of St. Malo in north-western France. Here there are *synodic* tides with a maximum range of 40 feet.

About two miles upstream from the mouth of the river, where the currents are least swift, a dam—2,330 feet long and 157 feet wide—is being built across the estuary and it will be 5 feet above the highest tides. By this dam a basin is created with an area of $7\frac{3}{4}$ square miles at high tides but reduced to 1.45 square miles at lowest levels. The maximum operating head will be about 30 feet.

This installation is to develop power of 342,000 kw. (458,000 hp.) at 10,000 volts by means of 38 turbo-electric units mounted in the dam. A specially designed axial-flow low-head hydraulic turbine and enclosed submerged but accessible electric generator, known as the "bulb type" and the "well type", have made it possible to have so many units in the

dam and to use them for generating and also for pumping. The delivery of power will be interrupted twice in each cycle of the tides for periods of about 2 hours each, a necessary feature in this one-pool system. During these intervals the turbines will serve as pumps.

In the normal sequence of operations, the turbines will drive the generators for about $8\frac{3}{4}$ hours of each tidal cycle—for half of this total time, water will flow from the basin to the sea and for equal time with reversed flow—and they will pump for about 4 hours, part time into the basin and part time into the sea. The inward pumping first will raise the basin level and thus increase the operating head for the first 4 hours of power output; the second pumping will lower the basin level and again increase the operating head for the second 4 hours of load. Thus the pumping operation will add energy to the water passing through the turbines in both directions and prove to be an economical feature of the installation.

Construction of the dam for this project was commenced in 1956. Three of the turbo-electric units were intended to begin operating in 1960 and the remainder in 1963 but the schedule has been delayed. This plant is expected to be the first tidal-electric power development in the world. It will be connected to a 50-cycle power network in the neighbourhood and will serve to augment the power supply in accordance with its schedule of operation.

French Proposals. In contrast to the relatively modest Rance project, two other French proposals are really fantastic. Both are one-pool systems with double emptying and double pumping.

Baie St. Michel. This bay, situated near the River Rance, has a synodic tide range of 41 feet. It is proposed to build earthworks and a dam totalling about 23 miles in length in the English Channel—from the French mainland to the Chausey Islands and back to the mainland. This dam would accommodate 1200 turbo-electric units and provide a basin with a storage area of 194 square miles at high level. This proposal would develop 5,000,000 kw. (6,700,000 hp.) and would flood the River Rance project rendering it inoperative.

Minquier Islands. These islands are British owned, part of the Jersey Island group. A synodic tide range of 41 feet applies here. The proposed dam and earthworks, from the French mainland out to the Minquier Islands in the English Channel and back to the French coast, would be about twice as long as those of the Baie St. Michel-Chausey Islands scheme, with twice as many turbo-electric units, and would completely

envelop that proposal. Storage area of 310 square miles would be obtained with resulting power development of 8,000,000 kw. (10,700,000 hp.).

When the data of the above three sites or plans are compared they show clearly the rising ambitions of the French engineers.

COMPARISON OF FRENCH ONE-POOL PROPOSALS

	River Rance*	Baie St. Michel	Minquier Islands
Total length of dams and earthworks	2330 ft.	23 miles	50+ miles
Area of basin, maximum	$7\frac{3}{4}$ sq. miles	194 sq. miles	310 sq. miles
Range of tide (synodic)	40 feet	41 feet	41 feet
Operating head	30 feet	31 feet	31 feet
Number of turbo-electric units	38	1200	2000
Capacity of generators	9000 kw.	9000 kw.	9000 kw.
Total capacity of development	342,000 kw. (458,000 hp.)	5,000,000 kw. (6,700,000 hp.)	8,000,000 kw. (10,700,000 hp.)
Maximum instantaneous operating head	80%	80%	80%
Average operating head	39%	39%	39%
Auxiliary stabilizing station	National Network	National Network	National Network

*Project under construction.

These proposals, Baie St. Michel and Minquier Islands, would involve enormous projects requiring many years to complete—10 and 20 years respectively. Modern engineering, however, can remove mountains and construct long causeways in deep water, e.g. the Canso Causeway in Nova Scotia, 4,200 feet long, 185 feet maximum depth of water, so probably can build such enormous tidal power plants as now are planned.

Soviet Arctic-Circle Proposal. The Soviets are contemplating a 2000-unit tidal-electric installation with a 62-mile dam across the mouth of Mezen Bay on the White Sea, near the Finland border, with capacity probably 8,000,000 kw. It is proposed, however, to build first the thermal-electric stabilizing station with capacity of 2,400,000 kw. (3,200,000 hp.).

Other One-Pool Tentative Plans. A tidal power scheme in the Bristol Channel, the Severn estuary on the west coast of England, has been under consideration since 1949. Here there is a 47-foot tide and tidal bore. A dam 6,825 feet long with 32 large turbo-electric units would be required. The British "grid" would serve as the stabilizing power network. It was planned to operate this tidal plant on the "H" system already described.

Solway Firth, on the west coast border-line of England and Scotland, is another prospective site for tidal development where much more power could be obtained than in the Bristol Channel but likely longer dams would be required. Also, Morecambe Bay appears worth developing.

The Bay of San José, on the east coast of Argentina, is a one-pool site where a relatively short dam would close the outlet. A total of 376 turbo-electric units are considered. Near-by is the Deseado River where another tidal power plant is possible.

Two-Pool System. In distinct contrast to the one-pool systems is another method used fifteen years ago for the Petitcodiac-Memramcook proposal in New Brunswick and this also is the basis for the investigations for the Passamaquoddy-Cobscook development. It is the two-pool system in which three dams, or earthworks, are required to provide the two basins for different water levels—the high pool filled by every high tide and the low pool drained by every low tide. The powerhouse would be in the third dam which separates these two basins.

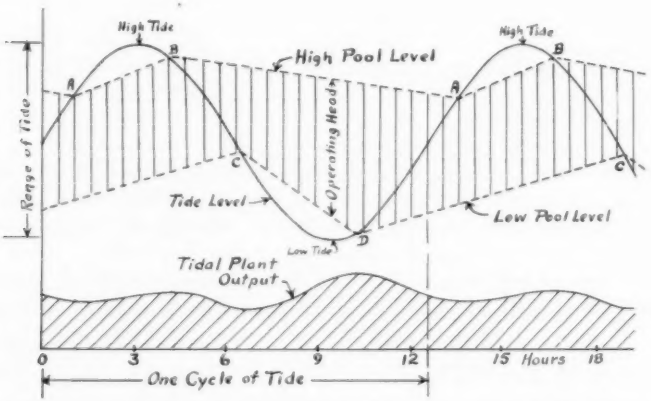

FIG. 7—Two-pool system: Passamaquoddy-Cobscook proposal. *A*: filling gates open. *B*: filling gates close. *C*: emptying gates open. *D*: emptying gates close. Generation for full tide cycle. Maximum operating head: 79% of tide range; average head, over cycle: 59%.

The principle of operation appears very simple (figure 7): (a) Whenever the tide rises to equal the water level in the high pool, the filling gates (*FG*) will open and the tide waters rush in until the tide reaches its maximum height on that cycle. These gates then will close to retain the water in this basin. (b) Whenever the tide falls below the level of the water in the low pool, the emptying gates (*EG*) will open and drain it into the sea until the tide rises again to equal the water level in the basin. These gates then will close to prevent further rise in this basin.

These operations will take place *automatically* at the proper time in every cycle of the tide. By this means, high levels will be retained in one pool and low levels in the other.

In the powerhouse, the turbines will draw water from the high pool and discharge it into the low pool. As there will always be an operating head of water, i.e. the difference in level between the two pools, the flow through the turbines will be continuous and in one direction only. Power generation, though varying considerably, will not suffer interruptions. The powerhouse can be much the same as the ordinary low-head plant constructed on tideless rivers and can use much the same types of turbine.

Due to the cyclic variation in output power, an auxiliary stabilizing station, either hydraulic or steam, will still be necessary with any two-pool tidal development—just as essential as for the one-pool systems.

The two-pool scheme is applicable only in locations where both of the required basins can be provided. Proposals for such installations in New Brunswick are using different arrangements for the dams, earthworks and powerhouse but all would operate on the same principle.

Bay of Fundy Two-Pool Proposals. There are several locations on the shores of the Bay of Fundy where the exceptionally high anomalistic tides could be developed for power. Studies have been made and proposals submitted to the Federal Government of Canada for two-pool installations at three sites:

(a) On the Petitcodiac and Memramcook Rivers which meet at their estuaries where they discharge into Shepody Bay.

(b) In Passamaquoddy and Cobscook Bays which adjoin each other on the international boundary between New Brunswick and the State of Maine.

(c) In Cumberland Basin and Shepody Bay which meet at the head of Fundy—well matched for area and providing one of the best sites in the world. This would be alternative to the Petitcodiac-Memramcook proposal, (a).

Proposal (a). The estuaries of the Petitcodiac and Memramcook Rivers meet at Fort Folly Point at the head of Shepody Bay where extremely high tides prevail. This site has been under consideration for many years for tidal power development and several schemes have been advanced, the latest being submitted in 1945. According to this plan, dams and earthworks, totalling 2.8 miles in length, would be built across both estuaries, with the powerhouse in a third dam, as shown in figure 8. The Petitcodiac River would be the high pool and the Memramcook

River the low pool, these basins having an area ratio of $2\frac{1}{2}$:1. The capacity of this station would be 240,000 kw. (322,000 hp.) using 30 turbo-electric units.

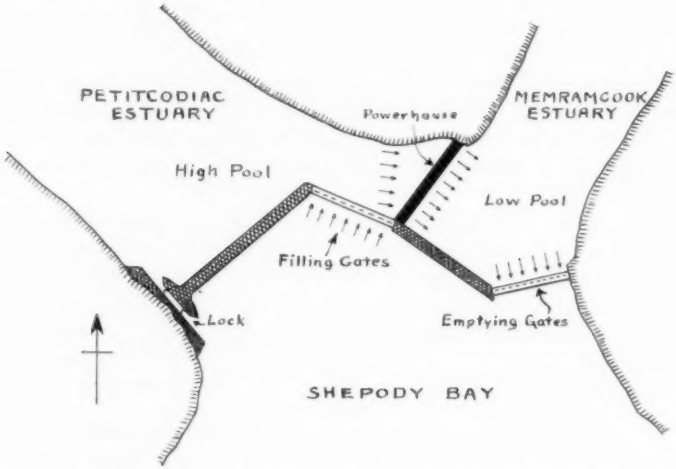

FIG. 8—Two-pool system: Petitcodiac-Memramcook proposal. Plan showing arrangement of dams, gates, powerhouse and lock for two adjacent estuaries, i.e. two confluent tidal streams. (Cross-hatched dams are rock fills.)

Although this plan appears quite feasible from an engineering viewpoint, the development did not materialize. The chief reasons against it were the unstable conditions in the beds of both estuaries as foundations for dams and the large amount of loose silt, mud and gravel in the bed of the Petitcodiac River, the high pool, which would present a serious maintenance problem for the hydraulic turbines.

This proposal may receive further consideration later but both astronomers and tourists alike will hope most earnestly that no dams nor earthworks shall ever be built across the Petitcodiac estuary to prevent the formation and obstruct the passage of that most famous phenomenal travelling wavefront known as the "Tidal Bore", a unique feature of this River observed to best advantage at Moncton.

Proposal (b). Passamaquoddy and Cobscook Bays meet at Eastport, Maine, and form an excellent site for a two-pool development on the international boundary. Many suggestions have been considered; the latest proposal, prepared by the International Passamaquoddy Engineer-

ing Board, was submitted to the International Joint Commission (Canada-U.S.A.) in October 1959, together with the Report of the International Passamaquoddy Fisheries Board on the possible effects of the project on local fishing.

These plans, which are under consideration by the Commission, involve a series of dams and earthworks, totalling 6.8 miles in length, from the Maine mainland connecting Moose, Deer, Pendleton and McMaster Islands, together with several small islets, to the New Brunswick mainland at Letite to make Passamaquoddy Bay the high pool while another series of dams and earthworks would connect Deer, Indian and Campobello Islands to the Maine coast at West Quoddy Head thus enclosing Cobscook Bay for the low pool, all as shown in figure 9. Both American and Canadian powerhouses are to be combined on Moose Island in the State of Maine. This plant would have a total capacity of 300,000 kw. (400,000 hp.) using 30 turbo-electric units with the latest "bulb type" generators.

Just why the Canadian powerhouse should not be in Canada is not clear when apparently a small rearrangement of the proposed dams and earthworks could allow it to be on Indian Island in New Brunswick.

This proposal includes larger bays than the preceding proposal but due to much lower tide range the total capacity is not increased proportionately. The area ratio of these bays is 2.46:1.

Proposal (c). Cumberland Basin and Shepody Bay, at the head of Fundy, are well matched for area, 1.33:1, and have the same very high tides as the Petitcodiac and Memramcook estuaries. About ten years ago, a Moncton engineer contended that a tidal development using these two pools would avoid the trouble from sediment in the Petitcodiac estuary and could have a capacity of 1,600,000 kw. (2,140,000 hp.)—the greatest natural site in the world. In April 1960, the LaSalle Hydraulic Laboratory at Lachine, Quebec, after studying this proposition for two years, presented their report to the International Joint Commission.

In this proposal, the Cumberland Basin, with area of 40 square miles, would become the high pool with Shepody Bay, area 30 square miles, for the low pool, dams and earthworks totalling 6.4 miles (figure 10). The powerhouse would be on the peninsula that separates these bays and contain 100 turbo-electric units of the newest bulb type with total power capacity of 800,000 kw. (1,070,000 hp.). This plant would be connected to the New Brunswick-Nova Scotia power pool at a point near-by.

The site is alternative to that of the Petitcodiac-Memramcook scheme, proposal (a), would preclude the development of the latter—or render it

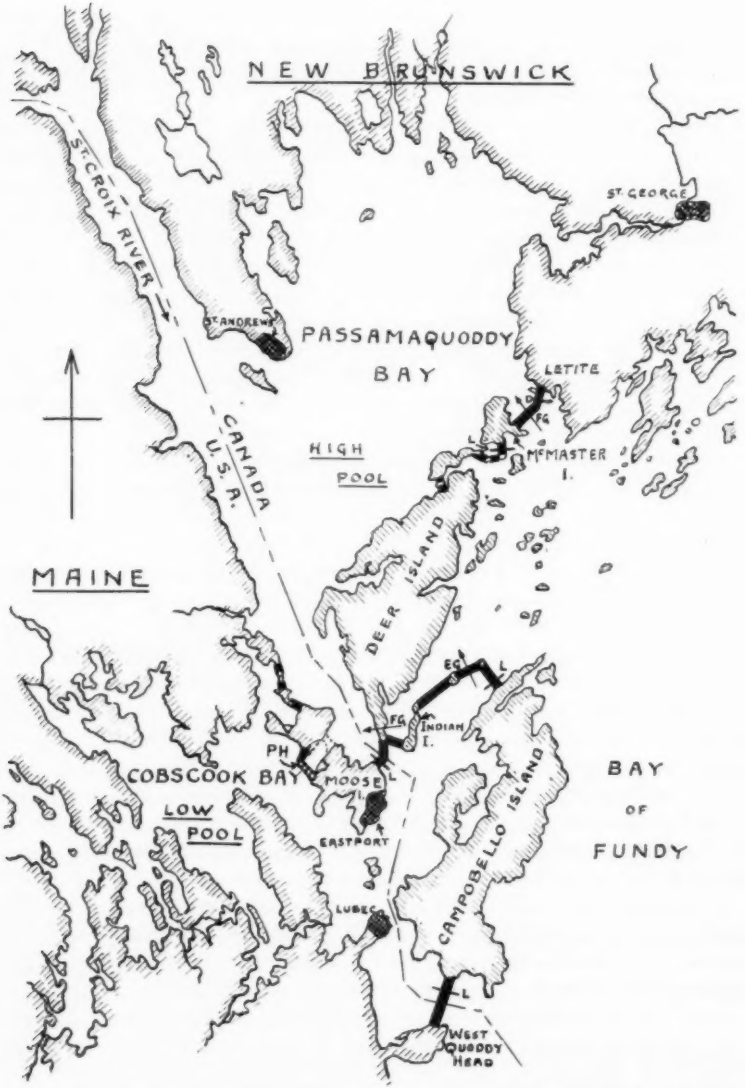

FIG. 9—Two-pool system: Passamaquoddy-Cobscook proposal. Map and plan showing arrangement of dams (black), filling gates (*FG*), emptying gates (*EG*), powerhouse (*PH*), and locks (*L*) for two adjacent bays.

FIG. 10—Two-pool system: Cumberland-Shepody proposal. Map showing positions of dams (black) in which filling and emptying gates would be installed, also probable location of powerhouse, *PH*. Fort Folly Point, marked by *X*, is the Petitcodiac-Memramcook site, at the confluence of these rivers, see figure 8. The proposed Chignecto Ship Canal, shown by heavy broken line from Baie Verte to the Cumberland Basin, will require complicated navigation locks in the dam at the mouth of this Basin.

inoperative if constructed previously—and would have over three times the power capacity. Unfortunately, this too would prevent the operation of the famous tidal bore on the Petitcodiac River, a very definite local attraction to both astronomers and tourists alike. (See Nov.–Dec. 1951 *Journal*.)

For any development requiring a dam across the mouth of the Cumberland Basin, consideration must be given to the operation of the proposed Chignecto Ship Canal which is to cut across the isthmus of the same name from the head of this Basin with its Fundy tides to Baie Verte on

the Northumberland Strait, the route being shown by heavy broken line in figure 10. In order to avoid serious interference with navigation passing through this canal, one or more locks will be necessary in the dam. These locks must be of large size to pass vessels of ocean-going dimensions and each must operate in both directions against 52-foot heads of water on either side—a very high lift for a single-step lock which would be of special design requiring the installation of heavy sector gates and a separate two-way culvert filling and emptying system—purely a navigation problem.

Comparison. There would be close similarity in the mode of operation of these three proposed developments. The following tabulation gives comparison of their chief features and also shows how they improve in some respects upon the corresponding characteristics of one-pool installations.

COMPARISON OF TWO-POOL PROPOSALS

Item	Petitcodiac-Memramcook Proposal (a)	Passamaquoddy-Cobscook Proposal (b)	Cumberland-Shepody Proposal (c)
Total length of dams and earthworks	2.8 miles	6.85 miles	6.4 miles
Area of high pool, maximum	17 sq. miles	101 sq. miles	40 sq. miles
Area of low pool, maximum	7 sq. miles	41 sq. miles	30 sq. miles
Range of tide (Anomalistic) (annual minimum and maximum)	21–52 feet	11.3–25.7 feet	22–52 feet
Operating head, average	26 feet	13 feet	26 feet
Number of turbo-electric units	30	30	100
Capacity of generators	8000 kw. (10,700 hp.)	10,000 kw. (13,400 hp.)	9,000 kw. (12,000 hp.)
Total capacity of station	240,000 kw. (322,000 hp.)	300,000 kw. (400,000 hp.)	800,000 kw. (1,070,000 hp.)
Variation in output power (annual minimum and maximum)	76,000–280,500 kw. (102,000–376,000 hp.)	95,000–345,000 kw. (127,000–462,000 hp.)	265,000–900,000 kw. (355,000–1,210,000 hp.)
Maximum instantaneous operating head in relation to tide range	82%	79%	74%
Average operating head, over one tide cycle, in relation to tide range	65%	59%	64.5%
Auxiliary stabilizing station	Steam-Electric	Hydro-Electric	New Brunswick-Nova Scotia Power Pool
Auxiliary stabilizing location	near Moncton, N.B.	Rankin Rapids, Me.	
Auxiliary stabilizing distance	25 miles (?)	175 miles	10–25 miles

Two-Pool Two-Powerhouse Scheme. The LaSalle Laboratory has advanced the studies of the Cumberland-Shepody site to produce much higher peak power by operating these pools as two separate and complete one-pool systems in a two-pool two-powerhouse plan, one powerhouse in each dam. These twin plants would offset their schedules by a few hours to prolong the period of continued power generation and by using a total of 200 new bulb-type units, which are capable of generating, sluicing water or pumping, could *double* the output available during operating periods—in comparison with the two-pool single powerhouse system.

There still would be interruptions of power, however, in each tide cycle but by tying these plants to the New Brunswick-Nova Scotia power pool, tidal power at this site could be used fully and to best advantage. This proposition is being given further study as it appears to have considerable merit.

Minas Basin Studies. The LaSalle Laboratory also has studied the possibilities of developing power, by both one-pool and two-pool systems, from the Minas Basin, in Nova Scotia, which has an area of 450 square miles with the highest tides in the world flowing and ebbing perpetually through the entrance channel but the construction of dams and earthworks in these deep waters and with the very strong reversing tidal currents presents a decidedly difficult problem, the cost of which work does not appear to be warranted. Such a fanciful project, however, is most interesting to contemplate. It would, of course, obliterate the excellent tidal bores on the Salmon and Shubenacadie Rivers that flow into this Basin.

Electrical Equipment. The greatest advance in electrical design for tidal power plants has undoubtedly been the development of the "bulb" and "well" type generators in enclosures which permit the turbo-electric units to be submerged in the flow stream and be more efficient and more suitable for both generating and pumping, and which results in narrower units allowing more of them to be placed side-by-side in a given length of dam structure. Prototypes of these new special turbo-electric units, both bulb and well types, have been tested thoroughly under actual operating conditions in French installations at Argentat and St. Malo and appear to be fully satisfactory for one-pool tidal power plants.

The generators will be of low-speed alternating-current types driven directly by the turbines and will run in synchronism in groups. The whole station may be one group or divided into groups. In one-pool systems, the generators will act as synchronous motors for parts of the tide cycle and drive the turbines as pumps.

The controls probably will provide standard automatic switching to take care of reversals of the turbo-electric units for pumping, on one-pool systems, and also to transfer load to the tidal station and from it to the auxiliary stabilizing station, with either system, as the tides rise and fall.

In any case, the electrical equipment does not appear to present unusual or serious problems in tidal power development.

Effects on Navigation. In all proposals for tidal-electric installations, locks are provided for passage of ships between the basin ports and the sea.

In the high pools of two-pool systems it is expected that conditions for navigation will be improved because the water levels will not fall so far from original high-tide levels—only about half as much as previously. In low pools, with range in water levels also cut in half, lowering of many wharves, docks etc. probably will be necessary but the reduced variation should give more stable conditions for navigation here also.

When the low pools have been stabilized at the lower levels, however, with industry's facilities depending upon the continuance of such levels, the consequences of a breach in the dams or earthworks which are protecting those lower levels from the sea could be disastrous by flooding —possibly even worse than the failure of a high river dam.

Conclusions. From a world-wide study of the types and ranges of tide in the various bays, inlets and estuaries, and considering their distances from present or probable load centres where power may be sold, it would appear that tidal-electric projects for many years to come will be confined to the Atlantic coasts and those to the north where the synodic tides run on within the Arctic Circle.

From the engineering standpoint, the generation of power by the ocean tides on a very large scale now appears quite feasible and can be used to augment existing power supply in certain areas. However, in the matter of economy, operation and maintenance there are some unanswered questions though no serious electrical problems.

Once started, the long dams and earthworks must be carried through to completion before *any* turbo-electric units can be operated. An auxiliary stabilizing generating station, with capacity about equal to the maximum variation in output of the tidal station, must also be built in order to give a steady supply to consumers. A sufficiently large load demand within a reasonable distance is required to justify the expenditure for construction of both of these plants.

Operation, though primarily automatic, will require considerable attention due to the frequent, more or less continuous shifting of load to and from the tidal station but the net result and advantage will be additional power for sale.

As to maintenance, the extensive dams and earthworks in some cases are exposed to the severe ravages of the sea and consequent erosion and damage which would be extremely difficult to repair. Metal machinery, the many turbines, being always submerged in seawater, would be subject to corrosion probably even more rapid than in fresh-water installations.

In comparison with tideless rivers, the tides have two very great advantages where generation of power is involved, namely (a) their

height, time of arrival and, therefore, the possible power available can be predicted with fair precision far into the future and (b) they are not affected by flood and drought conditions which cause such seasonal variations in the flow of rivers.

With either a one-pool or a two-pool system the maximum operating head obtainable appears to be about 80 per cent. of the tide range pertaining on any particular cycle. The average operating head, however, increases with improvements in the method used, as follows:

One-Pool	Simple emptying scheme	28% of tide range
	Double emptying scheme	39% of tide range
Two-Pool system		59% of tide range

Higher percentages may be possible in some cases but whether the necessary changes or improvements would be practical and economical may be questionable.

The average operating head is one of the two important factors that determine the power available. A higher operating head maintained over the full cycle means a more efficient rectification of the tidal oscillations.

Comments and criticisms offered by those persons and industries who would be affected by tidal power development suggest that the need for power should take precedence over the wishes of the few who would prefer to retain the beauty of the countryside whereas others maintain that such construction of dams would tend to improve vacation lands by adding water recreation, and would draw industry and tourists to the area. This would depend upon the geographical location.

A development such as that proposed as an auxiliary stabilizing station at Rankin Rapids on the upper St. John River would provide much desired control of flow for other power plants downstream. This suggests that there may be some advantage gained by building the auxiliary power stations first and then adding the tidal plants later.

Navigation in the basins is very dependent upon proper sequence and correct timing of operations in the power plants. Certain malfunctioning or improper timing could cause disaster to ships. It therefore becomes essential that all power equipment be maintained in perfect working order at all times.

It is felt by some that a tidal power project can not be economical since there is too small a minimum power demand for too great a maximum installed capacity and this with minimum possible output occurring periodically at the times of maximum load demand. However, where an additional source of power can be found in the tides, the economy of a development will depend very largely upon the importance and amount of the local load requirement and possible sale of power.

New problems and lack of experience with this type of development open fields for further investigation. As with any untried project, when difficulties appear man rises to meet the occasion with suitable remedies. So may it be with tidal power development. The progress and operation of the first installation, on the River Rance in France, will be followed with keenest interest.

To the scientist, the tides of the oceans are an intriguing subject for thought, a truly astronomical phenomenon, and now there appears to have come a definitely practical application of their energy on a grand scale to help to satisfy the needs of mankind. Some of the proposals may be deemed impossible. To the engineer, however, "impossible" means merely that he has not just yet learned how to do it—but soon, perhaps, he will.

Words of Shakespeare, intended figuratively, assume today a very literal meaning in tidal power ventures:

"There is a tide in the affairs of men . . .
. . . and we must take the current when it serves."

(*Concluded*)

THE BRIGHT-LINE STARS OF CLASS B—II

By Dean B. McLaughlin

University of Michigan Observatory, Ann Arbor, Michigan

Types of Variation. So far we have omitted one of the most characteristic aspects of Be spectra: their variability. Not all are known to vary, and some have been practically constant for several decades. But among a group of 40 of the brightest Be stars that have been observed at Ann Arbor for many years, only 8 have failed to show convincing evidence of spectral changes. In about 6 of the 32 variable ones the changes are relatively small and might have been missed if they had not been scrutinized critically. This still leaves more than half of the 40 that have had conspicuous spectral variations at some time.

The variations are of three kinds: (1) changes in the ratio of intensity of the emission lines to the neighbouring continuous spectrum, called E/C variation; (2) changes in the ratio of intensity of the "violet" to the "red" component of double emission lines, called V/R variation; (3) appearance and disappearance of a "shell" absorption spectrum. The three types are not mutually exclusive. Some stars, so far as known, have only one type of variation, others two, and a few have shown all three. We shall concentrate mainly on V/R variation, and shall touch briefly on the E/C type, but we shall not attempt any general discussion of shell spectra here.

E/C Variability. The E/C variations are usually simply fading or strengthening of the bright lines without appreciable changes of width. Just in the nature of the case, this is the only kind of variation we can know in stars that are seen most nearly pole-on. In extreme cases the bright lines disappear entirely or emerge in a spectrum in which they were formerly unknown. Many other stars have less striking changes. Thus, β Piscium and 11 Camelopardalis have had their bright lines temporarily weaker than normal, but never inconspicuous. The cycles are irregular and many years in length. Pleione lost its bright lines in 1906, regained them in 1937.

The disappearance of bright lines may be interpreted as the loss of the envelope, after which the star is simply a rapidly rotating absorption-line B star. The process apparently is a very gradual leakage to space, not a violent ejection. Since the line widths do not change conspicuously, we are not dealing with a great expansion of the whole rotating envelope, but only with a diminution of the material in it. The reappearance of

bright lines has not been observed in sufficient detail to permit generalization. In π Aquarii a newly-appearing double emission was apparently preceded by very feeble components considerably more widely separated than normal. This suggests ejection of a ring of gas which expanded, with conservation of angular momentum, and finally stabilized at a distance of a few stellar radii. A somewhat similar process evidently occurred in γ Cassiopeiae during its very active stages, but in this case there were great variations of width that Baldwin (1940) interpreted as expansion of the shell with conservation of angular momentum. The lines finally became extremely narrow, then a broad double emission developed. Apparently a new emission envelope with broad lines emerged from the star before the old one with narrow lines disappeared.

V/R Variability. The usual type of *V/R* variation is a balanced shifting of intensity between the two bright components into which the emission line is divided by the central absorption. The total intensity of emission remains nearly unchanged. In extreme cases one component may nearly disappear. More commonly, the maximum ratio is about 3:1.

Conspicuous shifts of the central absorption and the emission accompany the *V/R* changes. It is not surprising that the phenomena have sometimes been described as a shifting of the absorption across a fixed emission, for the intensity changes are qualitatively like those that would be produced in that manner. When the violet emission is strong, the absorption line is shifted towards the red; when the red emission is the stronger, the absorption is negatively displaced. Measures on the outer edges of the emission *at* Hβ *and higher lines,* however, show that the emission shifts in the *same direction* as the absorption, keeping the latter nearly central. There can no longer be any doubt of this, for it is shown by very long series of observations of four *V/R* variables: 25 Orionis (Dodson 1936), β Monocerotis A, H.D. 20336, and π Aquarii (McLaughlin 1951, 1958a, b, 1959). Figure 4 shows schematic profiles to illustrate the nature of the changes.

The preceding statement may *seem* to be a direct contradiction of one by Miss Underhill (1959) which is as follows:

> The changes in the apparent relative strength of the violet (*V*) and red (*R*) components of the emission feature are caused by a strong absorption core shifting across the stationary emission feature. This simple explanation of the well-known *V/R* changes in shell stars was suggested by Merrill and Sanford (1944) to explain their observations of 48 Librae, and it is confirmed by detailed study of the Hα profile of 48 Librae in recent years.

The contradiction is *only apparent* for we are discussing different things: the Hα profile as against that of Hβ and higher lines of the Balmer series.

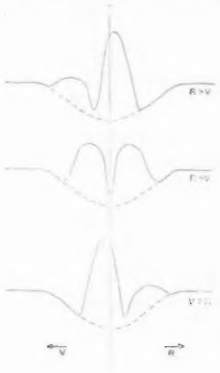

FIG. 4—Typical profiles of hydrogen lines in a *V/R* variable spectrum, showing Doppler shifts. The vertical line represents undisplaced position of line.

The edges that Dodson and I have measured are those of an emission that extends about ±200 km./sec. from the central absorption. We shall call this the "narrow emission." Miss Underhill's statement describes the relation of the central absorption to a much wider hazy emission that extends to ±600 km./sec. and is seen *only at Hα*. Upon it is superimposed the narrower structure, of about the same width as at Hβ, Hγ, etc. The profiles of the two merge gradually, so that edge measurements on the narrow emission at Hα might be difficult. This relationship of the narrow emission to the wider hazy one, as well as the absence of the latter at Hβ, is very well shown by the profiles determined by Miss Underhill (1954, p. 384).

Finally, in this connection, it is worth while to quote an independent observation described as follows by Merrill (1952):

> The decrease in intensity of the emission on the side towards which the dark line shifts is characteristic of shell spectra. This behaviour suggests at once that the emission moves less than the core, or might even be stationary. A comparison of the tracings of Hβ in β Monocerotis and a few approximate measurements indicate that the emission as a whole shifts in the same direction as the core, but by a smaller amount.

Examples of V/R Variation. Figure 5 shows the velocity curves for the central absorption line and the red and violet outer edges of Hγ in H.D. 20336. The three velocity curves run nearly parallel, so that the absorption remains nearly central. Hβ and Hδ, the only other lines measured, show the same behaviour. The amplitudes of the curves are about 100 km./sec., nearly half of the distance between the absorption and an outer emission

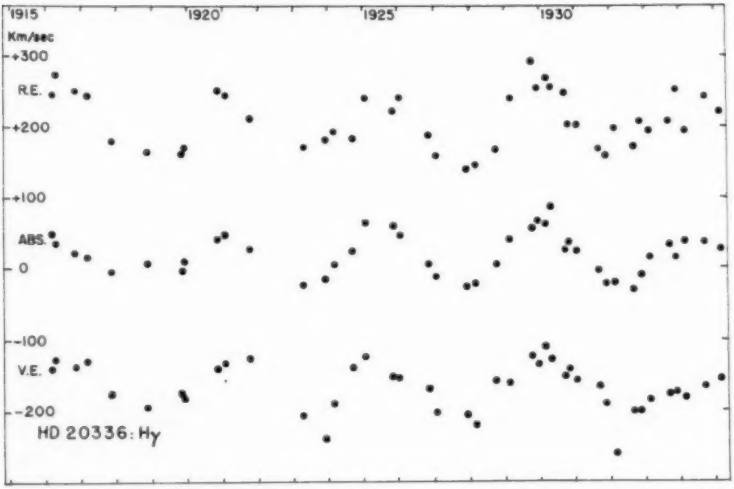

FIG. 5—Velocity curves of $H\gamma$ in the spectrum of H.D. 20336. *R.E.* = red emission edge; *Abs.* = central absorption line; *V.E.* = violet emission edge.

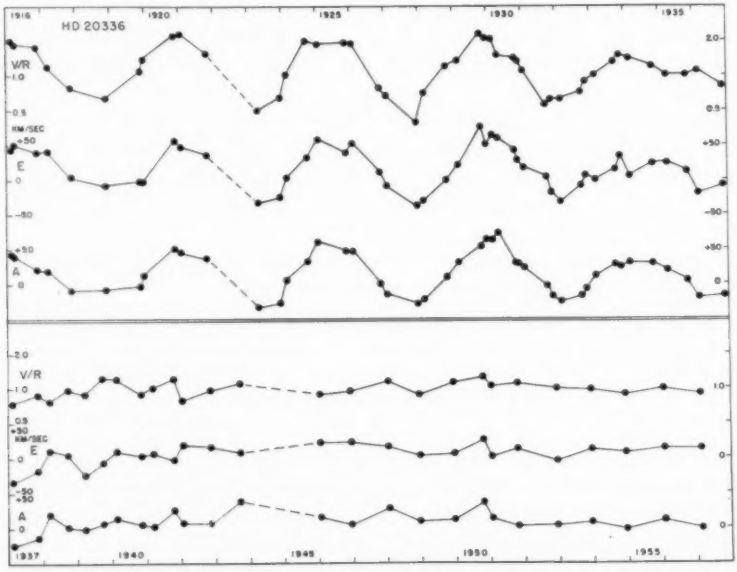

FIG. 6—Velocity and V/R curves of H.D. 20336. E = velocity of emission (mean of outer edges); A = velocity of central absorption.

edge. If the emission did not move, the motion of the absorption should cause a very large change of width of the emission components that would be obvious on visual inspection without measurement. No such change is seen.

The three curves in figure 6 appear very similar. The uppermost is the ratio V/R; the other two are the velocity curve of the emission (mean of the outer edges) and the velocity of the central absorption. These are means of Hβ, Hγ and Hδ. Each point is a mean of several spectrograms. The similarity of these curves is typical of V/R variables that have been studied in detail. The variations of H.D. 20336 appear fairly regular with a period of about 4.5 years. Immediately after the end of 1937 (figure 6 lower part), the variations practically ceased and in 1959 they had not yet resumed.

The changes of π Aquarii were quite irregular. Its variation curves are shown in figure 7. For a number of years before 1924 it was stable, with equal emission components and velocities near the mean of its later range. Conspicuous variations set in about 1924 and continued through 1935. After 1935 the emission became very weak on two occasions, and

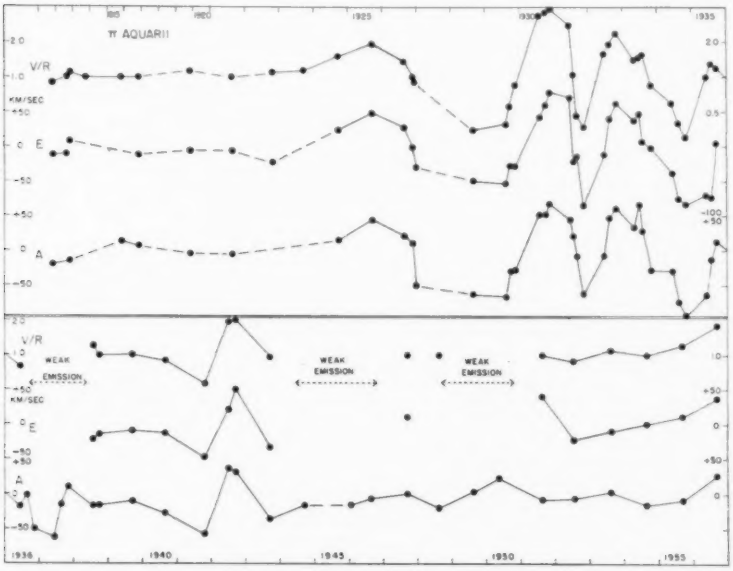

FIG. 7—Velocity and V/R curves of π Aquarii. Note that time scale is compressed for years before 1920.

even when it was present the variations were much reduced in amplitude. Beginning in 1956 conspicuous V/R changes and velocity variations set in again.

Both of the preceding stars have only moderate central absorption. The same is true of 25 Orionis, which was studied in great detail by Helen Dodson (1936, 1940). A fourth object, β Monocerotis A, has deep shell absorption at the hydrogen lines and distinct shell lines of Fe II. For at least 20 years before 1924 the shell was non-variable, the emission components equal, and the velocity at about its mean value. About 1924 variation set in with a "period" of 12.5 years, so that nearly three cycles have now passed, each with a greater amplitude than its predecessor. The variations resemble those of the previous three stars. The main points of difference are the greater accuracy of measurement of the strong shell lines and the somewhat smaller velocity amplitude, 40 to 70 km./sec. The correlation of V/R with velocities of emission and absorption is typical. The velocities measured on the Michigan 1-prism and 2-prism plates agree satisfactorily with Merrill's (1952) measures of coudé spectra.

The shell absorption lines, including those of hydrogen, become quite weak about the time when V/R changes from less than 1 to greater than 1.0 and the velocity passes the mean value on the rising branch of the curve. The weakness of the lines is appreciable for nearly a third of the period, with centre about this phase. Decline and recovery are approximately symmetrical. Miss Underhill (1957), found a marked weakening of metallic shell lines in 48 Librae in 1956 when the red emission was still strong and the velocity negative. This was near the phase at which the shell absorption of β Monocerotis A first weakened.

Unfortunately the stars are not unanimous. During its spectacular changes, γ Cassiopeiae had a strong shell absorption spectrum on two occasions. Both times were almost precisely at the same V/R phase as that of the *weakest* shell absorption in β Monocerotis A! However, the absorption velocities of γ Cassiopeiae were discordant with the usual relation between velocity and V/R.

The Rotating-Pulsating Model. In all probability, ϕ Persei, with a period of 126 days, is a binary and its V/R variations are in some way related to its orbital motion. The periods of most V/R variables are several years in length, and some of them are highly irregular. Binary motion, as a general explanation of their spectral changes must be ruled out, though a binary may simulate a V/R variable.

Some years ago I proposed the rotating-pulsating model to account for

the close relation between V/R and the radial velocities (McLaughlin 1931, 1933). We have already seen how the purely rotating extensive atmosphere will give equal emission components and a central absorption. If an expansion is now superimposed on the rotation, we obtain figure 8. Two alignments of emitting and absorbing atoms are depicted, one in the receding parts of the rotating cloud and the other on the approaching

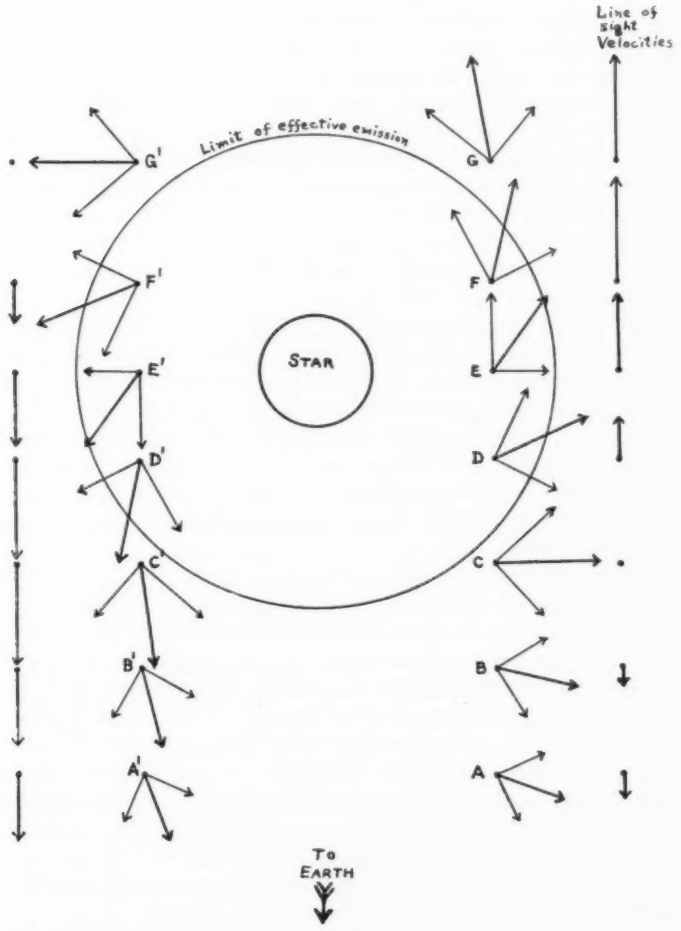

FIG. 8—The rotating-pulsating model of a Be star. The expanding phase is shown.

side. The receding atoms *D*, *E*, *F*, emit radiation that cannot be absorbed appreciably by the atoms *A*, *B*, *C* in the outer atmosphere, since there is a large relative velocity of the two groups of atoms in the line of sight. The red emission component therefore shines through strongly. It is quite otherwise with the approaching side of the atmosphere. The line-of-sight velocities of atoms *D'*, *E'*, *F'* are so nearly the same as those of *A'*, *B'*, *C'* that we expect strong absorption to overlie the violet emission component, which is therefore much weakened. Atoms between the star and the observer (not shown) have a velocity of approach because of the expansion and produce the central absorption shifted towards the violet.

It is fairly obvious that a systematic inward motion of all atoms would lead to the opposite type of profile, violet component greatly exceeding the red. Qualitatively this oversimplified model appeared very promising. However, it was never developed further, partly because the spectacular changes of γ Cassiopeiae showed so many features that conflicted with it, and partly because of grave doubts as to the possibility of having smoothly cyclic reversing motion in the whole atmosphere. The main reasons for my skepticism were three:

1. The long cycles of most *V*/*R* variables would require enormous motions that are very difficult to believe, especially the return of practically all the ejected material to a small region close to the star.

2. The accumulation of great amounts of ejected gas outside the emitting region ought to cause appreciable changes in the absorption line strengths. No such effects are seen in cyclic *V*/*R* variables, except for β Monocerotis A and 48 Librae. In these the shell lines *weaken* at just the phase where they should be *strengthening* if they represent accumulating outer gas.

3. Attempts to account for the bodily shift of the emission failed. The rotating-pulsating model appeared to demand that the absorption shift across the emission, and that the latter remain nearly or quite fixed. This was contrary to the observations.

In the meantime, Sobolev (1947) has made a very considerable advance in the interpretation of bright-line spectra. Previous attempts had involved the tacit assumption that the envelope was transparent. Sobolev considered an extensive atmosphere of great optical depth in the lines arising from excited states and calculated profiles that result from the differential Doppler effects. In particular, for a rotating and expanding atmosphere he obtains a profile with the red component stronger and the absorption shifted negatively, in general accord with my suggestion.

But the profile obtained by Sobolev is precisely the type that gave rise

to my objection (3) above. The edges of the emission remain nearly in the same place as for the rotating model, and the absorption is shifted off the centre towards the violet. I had long suspected that it would be necessary to disown my own hypothesis. Sobolev's calculations tend to confirm these suspicions.

If the rotating-pulsating model is to be retained at all, some mechanism must be found that will cut off the outer edge of the stronger emission component. Occultation, which I first naively suggested, simply will not work. Absorption appears to be the most likely other possibility. There does appear to be a conspicuous absorption border next to the stronger emission. I suggested that it was simply the deeper part of the underlying absorption profile uncovered by the shift of the emission. However, Miss Dodson (1936, p. 196) found that the phenomena in 25 Orionis were much more complicated. The observations may admit of interpretation in terms of an absorption line that cuts off the strong emission edge, but there is nothing in the model to suggest how such an absorption might originate. Therefore it seems advisable to explore other possible models.

Intermittently Expanding-Rotating Model. Alternation of expansion and quiescence offers some possibility of accounting for V/R variation. Consider the situation illustrated in figure 9, where the inner emitting region is rotating and expanding, while the outer absorbing atmosphere is merely rotating. Due to differential Doppler effect, the violet emission will suffer little absorption in the outer layers, while the red component will be partly absorbed. The effective location of most of the absorption has been shifted to the receding side of the rotating atmosphere.

A possible sequence of events can be pictured somewhat as follows. First, the entire rotating atmosphere gives equal emission components with a central absorption. Expansion begins in the inner emitting region, the violet component strengthens and the red one is weakened by absorption. When the outer absorbing region has begun to expand, the inequality will reverse, and we shall have the situation shown in figure 8, already discussed. Finally, the outer absorbing region is blown away entirely, while the expansion in the inner region slows down and ceases. Then a new cycle begins.

While such a process might produce a type of V/R variation, it seems unlikely that it would result in the smoothly cyclic behaviour that characterized H.D. 20336 and β Monocerotis A. If the motion of the inner region is communicated to the outer, the long duration of the phases of strong violet components implies a tremendously extensive atmosphere whose rotational velocity would surely be much lower than

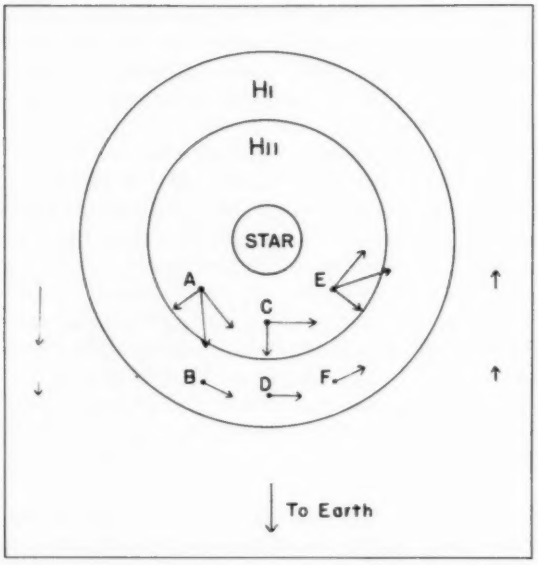

FIG. 9—The intermittently expanding model of a Be star. The phase shown is that of expanding inner atmosphere, but purely rotating outer layers. Atoms at *B* and *D* do not absorb radiation from *A* and *C* respectively, but atoms at *F* do absorb radiation from *E*. (See line-of-sight components of velocity at left and right.)

those we observe. Intermittently expanding atmospheres of this type may very well exist, but the slow cyclic V/R variables are not to be identified with them.

Eccentric Rotating Model. In his first paper on the rotating model, Struve (1931, p. 103) suggested that V/R variation might be accounted for by rotation of the line of apsides of an elliptical ring of gas. This idea was not developed further, perhaps because a *ring* of gas does not account so well for most of the phenomena of Be stars as does a disk. However, it seems worth while now to explore its possibilities.

The disk may be considered the sum of a number of gaseous rings with different radii. If the rotation of the disk were seriously disturbed (for example, by the sudden addition of much newly ejected material) the motions of the gas would become elliptical, and the disk would be eccentric, the sum of a number of confocal elliptical annular elements. Doubtless there would be much turbulent mixing and interference, but in a simplified model we shall neglect this. One of the rings is illustrated

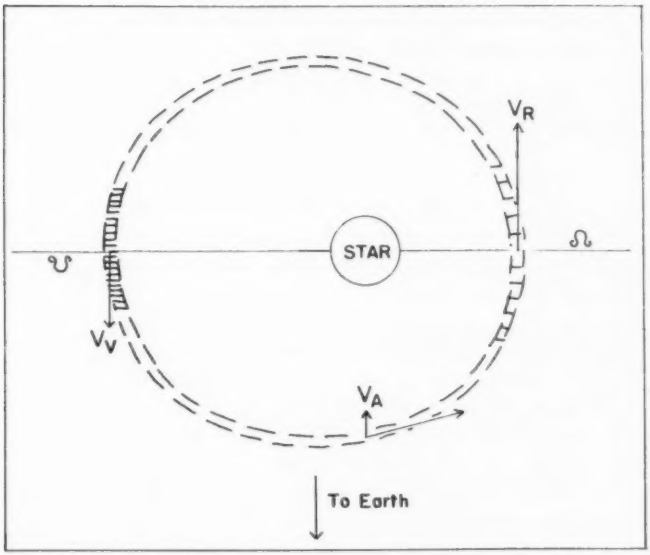

FIG. 10—Velocity components of an elliptical gaseous ring. V_v = violet component velocity; V_R = red component velocity; V_A = central absorption velocity.

in figure 10, where the major axis is taken coincident with the line of nodes and periastron is at the receding node.

The radial velocity of an atom in the ring is represented by the same expression that serves for the motion of a component of a spectroscopic binary

$$V = \gamma + K e \cos \omega + K \cos u,$$

where γ is the centre of mass velocity (the radial velocity of the star in this case), K the semi-amplitude of velocity, e the eccentricity, ω the longitude of periastron measured from the receding node, and $u = v + \omega$, the longitude in the orbit measured from the node. For the orientation pictured in figure 10, $\omega = 0$, and the velocities of the edges of the emission will be

$$V_R = \gamma + K(1 + e) \text{ and } V_v = \gamma - K(1 - e).$$

The mean of these is $\gamma + Ke$. The absorption will be formed by atoms at inferior conjunction, for which $u = 270°$, so that the absorption velocity is

$$V_a = \gamma + Ke.$$

In other words the absorption is central in the emission.

If the line of apsides rotates through 180°, we shall have

$$V_R = \gamma + K(1 - e) \text{ and } V_v = \gamma - K(1 + e).$$

The mean of these is $\gamma - Ke$. The atoms at inferior conjunction also have

$$V_a = \gamma - Ke,$$

and the absorption is still central. Thus the eccentric rotating model accounts for the bodily shift of the emission and for the central position of the absorption regardless of the orientation. The semi-amplitude of the absorption velocity is Ke.

The variation of V/R is accounted for by the crowding of the orbiting gas at apastron and its relative expansion as it passes periastron. The model automatically leads to the observed relationship of V/R to the velocity. Though we have considered only a single ring, the summation of a large number of confocal rings should lead to a similar result.

Finally, if the line of apsides is advancing, the condition $V < R$ (when $\omega = 180°$) will be followed one-quarter period later by a presentation of periastron towards the observer. The rarefaction of the gas at periastron should then result in a weakening of the absorption. This is precisely the phase relationship observed for the weakening of shell absorption in β Monocerotis A.

Martin Johnson (1958) examined the adequacy of the star's oblateness as the cause of rotation of the apse of a ring. Assuming fairly typical values for mass, radius, and rotational velocity, he obtained a period of the order of 2,000 days for the apse rotation, and hence for V/R. From this point of view the model is not quantitatively impossible. The irregularity of some V/R variables might be due to turbulent interaction of different parts of the extensive atmosphere whose periods of apse rotation would differ considerably.

Conclusion. There seems to be no good reason to doubt that the rotating model is a basically correct picture of a Be star. Further, the outer envelope is probably strongly flattened and has a radius several times that of the rapidly rotating star. Many differences between Be stars are simply the results of orientation relative to the line of sight. The shell spectra in particular probably represent the most nearly edgewise view.

We cannot be so confident in regard to the physical or geometrical interpretation of the V/R type of variation. The rotating-pulsating model fails to account for some important observed phenomena, and some of its implications as to dimensions appear inadmissible. A rotating

model with intermittent expansion fares no better. We are left with the eccentric rotating model which, so far as it has been examined, accounts for the observations and seems dynamically possible. At least it appears to be worth further investigation. Until it has been critically tested, we should suspend judgment as to the "true cause" of V/R variation.

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(*Concluded*)

CANADIAN SCIENTISTS REPORT—XXV

ASTRONOMY IN CANADA

In order that readers continue to be aware of research programmes being undertaken by Canadian institutions, the Journal presents the reports recently read to the National Committee for Canada of the International Astronomical Union.—Editors.*

Atomic Energy of Canada Limited

Work of Astrophysical Interest at Chalk River—Report by A. G. W. Cameron

The cosmic ray group under the direction of Dr. H. Carmichael is engaged in the routine monitoring of several components of the cosmic rays. The equipment includes a standard I.G.Y. neutron monitor, the two sides of which are recorded independently, a graphite-moderated neutron monitor, and two ion chambers, one enclosed in a spherical shell of lead and one bare. The ion chamber counting rates corresponding to several pulse heights are recorded. From these data it is possible to separate fluctuations in counting rates due to mesons plus electrons, to protons, and to events causing nuclear disintegrations in the gas of the ion chamber. Accumulated counts of all these events are recorded at five-minute intervals and are thereafter handled by data processing and plotting equipment.

By separating the intensity fluctuations of these various components of the cosmic rays, it is possible to identify the energy range of the particles incident on the atmosphere. From the nature of the fluctuations (sudden or gradual commencement, duration, and intensity), from the location of associated flares on the sun, and the presence or absence of Forbush decreases of the intensities of the galactic cosmic rays, it is possible to conclude a very great deal about the changing nature of the interplanetary medium in the inner solar system.

H. Carmichael and J. F. Steljes have made an extensive analysis of world-wide records of an unusual series of events occurring in the middle of July 1959. A flare on July 17 injected relatively low energy particles into the interplanetary medium at a time when there was a series of Forbush decreases. Following this event there were several brief occur-

*In Kingston, Nov. 25, 1960.

rences in which a significant modulation of the galactic cosmic rays was observed to take place. These modulations were localized to regions of the earth's surface only a few thousand miles across, since they did not appear in the data from all of the stations.

The accelerator group at Chalk River occasionally does experiments of interest to nuclear astrophysics, when these become possible within the general programme of investigation of nuclear reactions. Their equipment includes a 3 Mev. Van de Graaff accelerator and a 12 Mev. Tandem accelerator.

Recent work of interest includes a series of experiments carried on occasionally during the last three years by H. E. Gove, A. J. Ferguson, C. Broude, and A. E. Litherland. These were designed to investigate the properties of the 4.97 Mev. level in Ne^{20}. It has now been established that this level has spin 2 and even parity, and therefore that it makes the $O^{16}(\alpha,\gamma)Ne^{20}$ a resonant thermonuclear process. It follows that the helium-burning process probably makes large quantities of neon if it does not take place too rapidly, and this probably accounts for neon overabundances in "neon" and some "helium" stars.

Another investigation of considerable astrophysical interest is of the properties of nuclear reactions induced by bombarding C^{12} with C^{12}, carried out by D. A. Bromley, J. A. Kuehner, and E. Almqvist. The cross section curve exhibits an unusual resonance structure which has been interpreted by E. W. Vogt and H. McManus as indicating that carbon ions can easily be deformed and that they can interact to form molecule-like structures. The influence of this process on the thermonuclear reaction rate has not yet been evaluated. H. Reeves carried out some theoretical investigations of this reaction when he was at Chalk River in the summer of 1960.

Mrs. D. Ezer, an International Atomic Energy Agency Fellow from the Astronomy Department, University of Ankara, Turkey, spent a year at Chalk River during 1959 and 1960. She computed some massive main-sequence models of pure hydrogen stars with the help of the Datatron computer. These stars have very high central temperatures because the energy generation must be by the proton-proton chain. One interesting conclusion was that a pure hydrogen star of more than 25 solar masses will be unable to contract to its main sequence owing to formation of C^{12} by the triple-alpha process even during the Helmholtz-Kelvin contraction stage, thus leading to energy generation by a modified form of the carbon cycle.

For a number of years A. G. W. Cameron has been interested in theoretical problems of nuclear astrophysics and nucleogenesis. He has

investigated thermonuclear reactions producing neutrons and the synthesis of heavy elements by neutron capture processes. He has also investigated several other processes which seem to be responsible for synthesizing different parts of the periodic table of elements. Recently he has been investigating nuclear reactions at high temperatures and densities, with emphasis on mechanisms that may lead to nova and supernova explosions. Among these reactions are an interesting set of new processes which probably produce neutrino-antineutrino pairs at high temperatures, thus leading to very large rates of energy loss from stellar interiors at an evolutionary stage just past helium-burning.

Recently he has been interested also in the differences in the isotopic composition of atmospheric and meteoritic xenon. Suggested explanations of these differences have led him to develop a unified theory of star and planet formation which contains many new features.

Université de Montréal

Report by Hubert Reeves

Serge M. Lapointe of the Université de Montréal, and D. C. Rose of National Research Council have found asymmetry in the recovery from a very deep Forbush-type decrease in cosmic ray intensity.

The intensity-time curves for cosmic rays recorded at some thirty stations distributed all over the world were examined for structure in the recovery period from the third in a series of three closely spaced Forbush-type decreases which occurred in the middle of July 1959. It was shown that the structure of intensity peaks was regular and that these occurred at each station at the same effective local time, after correction was applied for the deflection of the particles in the earth's magnetic field. Evidence leading to the nature of the energy spectrum of the beam responsible for one peak was investigated. The spectrum of ordinary galactic cosmic rays was found to give reasonable agreement. This was assumed, and it was found that all this is consistent with the hypothesis that recovery from a very deep Forbush-type decrease is first apparent in directions making 15° and 165° with the sun-earth line respectively. The analyses suggested further, that during recovery from this deep Forbush decrease temporary openings appeared in the intensity-depressing mechanism which allowed intensity increases in limited directions.

Heavy ions reactions in stars have been investigated by Hubert Reeves. The experimental reaction cross sections for collisions between various "heavy ions" (C^{12}, N^{14}, O^{16}, F^{19}) has been analysed. Far enough

above the Coulomb barrier the asymptotic formula $\sigma = \pi R^2$ yields interaction radii (R) roughly equal to the sum of the radii of the colliding nuclei. However in the region below the Coulomb barrier the cross sections in all cases fall much too rapidly to be accounted for in terms of purely attractive (Wood-Saxon type) complex potentials. To match the experimental results one has to decrease progressively the interaction radii to almost unrealistic values, no matter what values were given to the other usual parameters. An analysis of these numerical results indicates that the inclusion of a repulsive core, followed by an attractive shell would get rid of such difficulties. It has already been pointed out that the rearrangement of nucleonic orbits which would accompany such a reaction might well give rise to a repulsive force, as in the case of molecules. More experimental work has been done on the very low energy yield of these reactions. The results are still being analysed. If the conclusions proposed above are found valid, the thermonuclear reaction rates will be much slower than expected. Then the neutron production through the $C^{12} + C^{12}$ process might be totally inexistant.

NOTES FROM OBSERVATORIES

Dominion Astrophysical Observatory, Victoria, B.C.

Dr. K. O. Wright is spending the academic year as Guest Professor in the Department of Astronomy, University of Toronto. Dr. A. H. Batten continued tenure for a second year of a N.R.C. Post Doctoral Fellowship. Dr. Y. Fujita completed his studies of spectra of the cool carbon stars in November and returned to Japan. Mr. W. R. H. White of the seismology division is spending the academic year at the University of British Columbia on educational leave. Dr. Anne B. Underhill is spending the winter quarter at the Institute for Advanced Study, Princeton, N.J., working with Professor Stromgren's group on problems of the theoretical prediction of stellar spectra.

R. M. Petrie and K. O. Wright attended the meeting of the National Committee for Canada of the International Astronomical Union held at Kingston in November. They participated also in the dedication ceremonies of the new Queen's University telescope. Dr. and Mrs. Petrie attended the dedication of the Haggard Hall of Science, and a two-day symposium at Western Washington College of Education. R. M. Petrie delivered the evening lecture on that occasion.

At the end of the year the Observatory received a complete aluminizing plant designed for coating the mirrors of the new telescope. The equipment has already been used to coat the 20-inch secondary mirror and performs very well. Early in February the 73-inch mirror was removed from the telescope and its cell preparatory to re-aluminizing. The coat has recently deteriorated after a record period of nearly 18 years' service! A new darkroom and observers' room have been constructed on the observing floor of the 66-foot dome thereby improving the facilities and amenities for carrying on night work with the telescope. The office building has been redecorated and plans have been completed for the installation of additional shelving in the library.

Observational work during the fall and winter has been concentrated on spectroscopic binaries. Favourable weather in January enabled material to be obtained for the completion of a number of second-epoch "orbits." The binary nature of Mizar B has been confirmed and the brighter component of ξ Cephei has been found to be a two-spectrum binary. The eclipsing binary AR Cassiopeiae has been found to exhibit a "rotation effect" in the radial velocities and the spectroscopic binary ψ Orionis has been found to have a slowly precessing orbit.

REVIEW OF PUBLICATIONS

Cosmic Radio Waves by I. S. Shklovsky. Pages xvi + 444; 6×9⅜ in. Toronto, S. J. Reginald Saunders and Company, 1960. Price $14.40.

An optical astronomer, accustomed to thousands of spectral lines and angles measured in seconds of arc might easily underestimate the contributions made by radio astronomy with its single spectral line and low angular resolution. This attitude would disappear while reading Shklovsky's *Cosmic Radio Waves*. For example, in absolute sensitivity he shows that radio telescopes far surpass optical telescopes; the minimum flux detectable with a large radio telescope would, if it were in the optical region, correspond to a star of 30th magnitude.

Unlike most earlier books on radio astronomy this work is devoted entirely to radio waves from the galaxy and beyond; there is no treatment of solar noise, meteors, radar, or emissions from the moon or planets. That a 400-page book can now be devoted entirely to cosmic radio waves indicates the progress since 1954 when Pawsey and Bracewell devoted only one-seventh of their book to the subject.

A clear distinction is made between observational results and their interpretation. For the general background radiation the observations are well presented as eighteen contour maps at various frequencies. For the discrete sources, data are given on position, spectra, angular extent and optical identification.

One of the most fundamental problems in radio astronomy is the understanding of the mechanism by which radio waves are generated in interstellar space. Various theories such as thermal emission and plasma oscillations are reviewed before advancing what now seems to be the solution to the problem, synchrotron radiation. This mechanism involves acceleration of relativistic electrons in a magnetic field. Optical polarization measurements are presented as evidence for the magnetic field and supernova explosions are suggested as the source of the high-velocity electrons. This theory can account for the cosmic ray spectrum as well as the non-thermal emission from most radio sources.

After a discussion of the 21-cm. hydrogen radiation, consideration is given to other spectral lines which might be observable. It is stated, without references, that the first attempt to observe the deuterium line was made in Canada. The information came as a surprise to this reviewer and his colleagues who were unaware that the experiment had been tried in this country. Perhaps the work was done as a defence project, became classified as a routine measure, and hence is only available to the Russians.

A new analysis of ancient Chinese documents and other relevant data leads to the conclusion that a supernova explosion is a fairly common galactic phenomenon; possibly two or three occur per century. It is reasoned that every 10^8 years the solar system may find itself, for some 10^4 of years, in the expanding shell of a supernova where the cosmic ray density would be much larger than at present. This leads to the exciting speculation that ". . . this might be the explanation for such paleontological phenomena as the wholesale extinction of the reptiles at the close of the Cretaceous period, or the exceptionally luxuriant growth of vegetation in the Carboniferous period. Indeed, the rise of life itself on the Earth may have been stimulated by a prolonged, powerful irradiation of primeval organic molecules, not yet living."

Although it is not intended as a popular book the treatment is generally descriptive rather than mathematical and should appeal to the amateur as well as the professional.

JOHN GALT

Cosmology (second edition) by H. Bondi. Pages 182; $5\frac{1}{4} \times 8\frac{1}{2}$ in. Toronto, Macmillan of Canada, 1960. Price $5.00.

As Bondi defines its range, cosmology deals with ". . . the largest set of objects to which our physical laws can be applied successfully."

This volume being the second edition of a book which first went to press in 1951, the reviewer was of course interested to see to what extent the drastic revision of the time scale of the universe by Baade and Sandage, the profliferating observational material from radio astronomy —both alluded to in the new preface—showed up in the last chapter where Bondi sets forth the "Present Position in Cosmology." He was frankly disappointed. The steady-state theory has in recent years been gaining in favour *vis a vis* the evolutionary cosmologies, possibly for the simple reason that new attitudes take a while to diffuse and their precepts to become widely known. Yet little of the optimism I expected to see was present. This seems an appropriate place to point out that the Cambridge group, during its period of greatest activity, did a great service in giving research in this subject a focus of argument which it had not had since the conflicts between Einstein and Milne during the 1930's over general relativity *versus* kinematic relativity.

The book is well written and deals fairly with the other cosmological theories of interest. Most readers delving into the book can be expected to be looking for the treatment there given of the Perfect Cosmological Principle and the extent to which *The fundamental assumption of the*

theory . . . that the universe presents on the large scale an unchanging aspect is borne out by the deduction from it that *Nebulae of all ages hence exist with a certain frequency distribution*. This leads to a further consequence of the theory with which the reviewer has always had a little difficulty. It is a stumbling block which is not entirely overcome by Bondi's statement that the steady-state theory is but another expression of the Copernican view that, if our terrestrially-obtained knowledge of the physical world can be applied to the universe at large, then our neighbourhood is "typical." Because the next deduction one would make from the theory's interpretation of the Hubble-Humason red shift would seem to be that if our descendants—or intelligent beings in galaxies other than our own—survive long enough, their vantage point for viewing the universe should become Methuselah's, and hence atypical. As a result of the continuous creation of matter, younger galaxies would have grown up around theirs and galactic groupings of the same or greater age would have disappeared over the visible horizon.

The discussion of those theories lumped together in Chapter XIII is, as Bondi admits, too brief to be adequate. It is in these that the greatest hope of new developments is to be found because of the avowed attempts of these theories to establish a closer link between cosmology and microphysics. The intense research going on in elementary particle physics and the increasing interest which high-energy particle physicists have been showing in cosmological questions augurs well for the approach taken by Eddington, Dirac, Jordan and others. Until recently this point of view was somewhat in disfavour. The newer attitude can be seen, for example, in T. D. Lee's article in the October 1960 issue of *Physics Today*, and in the anti-matter theory which brought Sagré the 1959 Nobel Prize.

J. A. Rottenberg

NOTES

Dedication of the Queen's Telescope

On November 25, 1960 the new Queen's University telescope was formally opened with astronomers from across Canada present. The ceremony, under the chairmanship of the Principal, Dr. W. A. Mackintosh, included a brief history of astronomy at Queen's University given by Dr. A. Vibert Douglas, Professor of Astronomy. The telescope was declared formally open by Dr. C. S. Beals, the Dominion Astronomer. The ceremony was held in Ellis Hall, the new Civil Engineering Building, at the base of the stairs leading to the roof where the telescope is housed. After this event the group was addressed in the auditorium of Ellis Hall by Professor T. Gold of Cornell University on the formation of the planets.

National Committee for Canada of the I.A.U., meeting in Queen's University, Kingston, Nov. 25–26, 1960. *Seated* (left to right): Miriam S. Burland, D.O., Ottawa; John F. Heard, D.D.O., Toronto; C. S. Beals, D.O., Ottawa; Ruth J. Northcott, D.D.O., Toronto; R. M. Petrie, D.A.O., Victoria. *Standing*: R. W. Tanner, D.O., Ottawa; Donald A. MacRae, D.D.O., Toronto; George R. Harrower, Queen's U., Kingston; Peter M. Millman, N.R.C., Ottawa; K. O. Wright, D.A.O., Victoria; Hubert Reeves, U. de Montréal, Montreal; A. G. W. Cameron, Atomic Energy of Can. Ltd., Chalk River; A. E. Covington, N.R.C., Ottawa; Malcolm M. Thomson, D.O., Ottawa; W. Wehlau, U. of Western Ont., London. Absent when picture was taken: A. Vibert Douglas, Queen's U., Kingston. (Photo by DEWAR.)

The new telescope consists of three instruments on one mounting: a 15-in. Cassegrain reflector, a 6-in. Catadioptic guide telescope and a 3-in astrograph. In addition to the new optical equipment, astronomical offices and laboratories are available. Although courses in astronomy were first offered in 1863, no permanently-mounted telescope has been available since 1946 when the observatory housing the 6¼-in. Alvin Clarke refractor was torn down to make way for a new building. Now, with the fine new optical equipment and laboratory space, Queen's University can provide good training in astronomy under Dr. Douglas. Radio astronomy was added to the curriculum with the appointment of Dr. George A. Harrower to the staff in 1955.

A business meeting of the National Committee for Canada of the International Astronomical Union, and a symposium on recent instrumental advances in astronomy rounded out the programme.

RUTH J. NORTHCOTT

RESTRICTION OF ASTRONOMICAL OBSERVATIONS BY SPACE OBJECTS

It has been estimated that there will be 5,000 man-made objects in orbit in ten years and in view of present trends it is hard to believe that at least some of these will not hamper or seriously restrict earth-bound astronomical observations.

When the Echo I satellite was orbited it became apparent that wide-field photography would become increasingly difficult. There are proposals to orbit as many as fifty Echo objects. The manufacturers of the Echo balloons say that they can make them up to 1,000 feet in diameter. A great number of balloons this brilliant would cause a great increase in the brightness of the night sky (and each would leave a very heavy streak across any photographic field). Probably such large balloons will never be made since the present trend seems to be toward the smaller, repeater-type satellites for communications systems. Therefore it is hard to understand why the N.A.S.A. is pushing the Echo-type system.

A possibly greater threat lies in plans such as the so-called Project Needles or Project Westford. Even after reading a detailed report on the proposal, it is difficult to evaluate the hazards of the orbiting dipoles. The bands may be faintly visible when first placed into orbit, but later will spread out. These dipole bands carry a great threat to radio astronomy. Project Westford is now in the hands of the Air Force and I am concerned that the interests of astronomy will not be considered. A potential danger here is that it may be decided that more or larger dipoles are needed, possibly in larger bands. The M.I.T. report by Mr. Morrow states that the dipoles measurably increase the penetration

hazard for any space vehicle. It is difficult to understand how the same interests that plan to launch vehicles can go through with any plan that will increase the hazards thereto. It is to be hoped that the first needles experiments will use the short-lived disposable tin-alloy dipoles mentioned in the M.I.T. report.

There now seems to be a battle shaping up between the military and the N.A.S.A. over the control of space projects. This alarms me because I feel that, once space plans come under the control of the powerful military interests, we may no longer have any recourse regarding harmful schemes.

Last year one of the Services proposed the orbiting of great quantities of sodium vapour. The result would have been a vast overall increase in the brightness of the night sky. If such an extreme plan were ever carried out, it would be a disaster for astronomy aside from the adverse psychological effects on the normal human being.

It has been only three years since the beginning of the so-called "space age" and already astronomy appears to be threatened. Our technology is moving at such a rapid pace that it is not pleasant to imagine what will be possible in a few years. I feel that it is only the most extreme space projects that will be harmful to astronomy. While spectacular gains will come when the series of orbiting astronomical observatories are put into operation, these advances might be more than neutralized by any great hampering of ground-based observations.

There is apathy among those who might be affected by harmful space projects. Unfortunately, once a harmful project is put into operation, it may take many, many years before the material returns to earth. Therefore, it is obvious that the time to fight these things is before they are done. Some sort of unified action by a great number of astronomers probably would represent the best method of countering this threat. It would seem that the best way would be to work through the International Astronomical Union and/or the American Astronomical Society or possibly the United Nations Ad Hoc Committee on the Peaceful Uses of Outer Space. Unless some form of definite and vigorous action is taken, I fear that astronomy will soon become hampered and that eventually (within five to ten years) many types of observations may become practically impossible.

The backbone of astronomy is routine observation from ground-based observatories; every effort should be made to see that this remains possible for an indefinite period.

Alan McClure
Los Angeles, California

VARIABLE STAR NOTES

By Margaret W. Mayall

The American Association of Variable Star Observers, Cambridge, Mass.

Miscellaneous notes of peculiarities of variation in some variable stars, noted from observations made by members of the A.A.V.S.O. during 1960.

000451 *SS Cas.* A faint maximum, 10.2 mag., was observed the first week in December 1959, followed by one of 9.8 mag. the last of April; and one of 9.0 the middle of September.

004435 *X Scl.* An 11.3 mag. maximum was observed in the middle of November. The 3 preceding maxima September 1958, June 1959 and February 1960 were brighter than 11 and the one in January 1958 was about 11.2.

004533 *RR And.* A faint (10.3) maximum was observed about the middle of August. The preceding one in September 1959 was 1½ mag. brighter.

005475 *U Tuc.* A very faint maximum, about 9.7 mag. was observed April 20.

005840 *RX And.* A Z Camelopardalis-type variable. Varied erratically between 11 and 13.

013238 *RU And.* Magnitude range increased to about 3 mag. during 1960.

013338 *Y And.* A 10th mag. maximum in the middle of July follows 9th mag. ones in 1958 and 1959.

021143 *W And.* A bright maximum (7.2) the last of September follows one a magnitude fainter in 1959.

021403 *o Cet.* A maximum was observed about July 15, mag. 3.2.

021937 *BI And.* Observations are needed for this interesting semi-regular variable. Its visual range is probably from about 10½ to 12.

022150 *RR Per.* Since 1955 the maxima of this star have been 10th mag. or fainter. In the past they have been observed as bright as 8.

022813 *U Cet.* An 8th mag. maximum the first of October followed one more than a magnitude brighter in February.

032443 *GK Per* (*Nova 1901*). Peltier observed a 1½ mag. rise from the middle of March to the end of April. Since then it has stayed around the 13th mag., its pre-nova brightness.

043274 *X Cam.* A bright minimum (11.6) was observed early in December following 13th mag. ones the first of March and mid-July.

050953 *R Aur.* A faint maximum, about 8.2, occurred in early October. There was a stillstand of nearly 100 days at 10.5 mag. on the rising branch of the curve.

051316 *XX Tau* (*Nova 1927*). Not seen during the year.

054319 *SU Tau.* This R Coronae Borealis-type variable was nearly constant at 9.5 mag. from the first of the year to the end of the observing season, and was still there when it was observed again in August. Toward the end of November it started to drop, and by the end of December it was about 12th mag.

054705 *CN Ori.* More observations needed of this faint Z Camelopardalis-type star.

063462 *RR Pic* (*Nova 1925*). Nearly constant at 11.7.

070122 *R Gem.* A faint maximum, about 7.6, early in April, followed one a magnitude brighter near the end of March 1959.

080835 *CP Pup* (*Nova 1942*). Constant at 11.1.

081473 *Z Cam.* This star varied throughout the year with minima at about 13th mag. and maxima ranging from about 10½ to 12.

093014 *X Hya.* More observations needed for this variable, to determine dates of maxima and minima. It varies from about 8½ to 13, well within the range of a moderate size telescope.

094211 *R Leo.* A bright maximum, nearly 5th mag. was observed about March 25.

095563 *RV Car.* A faint maximum, about 12.4, was observed in the middle of July.

101153 *W Vel.* A faint maximum, 9.5, the last of July, followed 8½ mag. ones in 1958 and 1959.

111561 *RY Car.* A very faint maximum, 13th mag. was observed near the middle of April.

123160 *T UMa.* A very bright 7th mag. maximum in the middle of January followed one of 8.4 in May 1959. Another maximum (7.8) was observed in the middle of September 1960.

143417 *V Lib.* A very faint 11th mag. maximum was observed near the end of August. The last well-observed maximum was 9th mag., in April 1959.

145971 *S Aps.* Nearly constant throughout the year, at about 10th magnitude.

151432 *U CrB.* A minimum of this eclipsing variable was observed by Gonthier on August 27.

153020 *X Lib.* Observations are needed for this variable. No good maximum or minimum has been observed for several years.

154428 *R CrB.* R Coronae Borealis started to fade soon after the first of the year, and dropped to 11th mag. by February 15. It continued to vary between 10 and 11 and then dropped to about 12½ near the end of April. It rose to nearly 6th mag. in August and then took another deep plunge to 12 the last of September. By December it had again brightened to about 7. This is one of the most interesting minima the star has had for about 20 years.

154615 *R Ser.* A faint maximum (7.9) was observed near the last of March. At the same time, Dr. Keenan reported (*H.A.C.* 1475) a very peculiar spectrum, with abnormal TiO bands, the line λ 7054 weak, AlO in emission, and ionized Sr very strong.

154715 *R Lib.* Observations needed.

155526 *T CrB* (*Nova 1866, 1946*). Constant since 1956.

155823 *RZ Sco.* Range increased to about 3 magnitudes again.

160519 *W Sco.* Observations needed.

162119 *U Her.* A faint (8.6) maximum in early October follows a 7th mag. one in 1959.

163360 *TX Dra.* Range of variation decreased to about half a magnitude in 1960.

165636 *RT Sco.* A bright maximum (8.2) observed early in March followed a 10th mag. one in 1959.

172486 *S Oct.* A bright (7.6) maximum the first of July continues the alternation of bright and faint maxima.

174406 *RS Oph* (*Nova 1898, 1933, 1958*). Fluctuated between 10 and 11 throughout the year.

180445 *DQ Her* (*Nova 1934*). Near 14th mag. most of the year.

184205 *R Sct.* A two-magnitude range was observed in the latter part of the year.

185213 *Nova Her 1960.* By the end of the year, the nova had faded to about 11.8.

185851 *BL Tel.* A minimum of this eclipsing star was observed by deKock the first of April. He has observed the following 4 minima: 2433930, 10.4; 4690, 8.9; 6252, 9.5; and 7028, 9.6. These minima indicate a period of 776 days.

191033 *RY Sgr.* Fluctuated between 6 and 7 during the year.

194048 *RT Cyg.* A bright (6.6) maximum in mid-February was followed by a faint (7.6) one the last of August.

194632 *χ Cyg.* A marked stillstand at about 7.2, for about 50 days on the rising branch of the curve preceded a 5th mag. maximum the last of October.

195553 *V476 Cyg* (*Nova 1920*). About 16th mag. during the year. Peltier found it 13.8 early in September, but according to Taboada and Cragg it was again 16 in October and November.

195656 *RR Tel.* About 9.5 most of the year, with some rapid variations suspected between 9 and 10.5.

204215 *U Cap.* Observations are needed to determine dates of maxima and minima.

212814 *Y Cap.* Another rather faint variable which needs observing.

221255 *CP Lac* (*Nova 1936*). A little fainter than 15.

232848 *Z And.* This very peculiar variable was between 9 and 10 until August, when it began to fade and was one magnitude fainter by the end of the year.

Observations received during November and December 1960: A total of 11,616 was received: 5,380 from 87 observers in November, and 6,236 from 108 observers in December.

Observer	Nov.		Dec.		Observer	Nov.		Dec.	
	Var.	Ests.	Var.	Ests.		Var.	Ests.	Var.	Ests.
Adams, R. M.	122	232	121	225	Diedrich, DeL.	6	8	4	4
Alcazar de la Riva, J.	...	...	2	2	Diedrich, G.	8	9	8	9
Anderer, J. A.	...	...	2	2	Drahos, D.	4	13	5	12
Anderson, Carl	10	16	12	15	Dueck, A.	...	...	3	3
Anderson, Curtis	65	114	5	5	Engelkemeir, D.	11	27	14	32
Astudillo, J.	...	...	6	14	Erpenstein, O. M.	12	20	10	10
Axelson, K.	9	19	10	17	Farmer, R.	2	2	...	...
Ayala R., H.	13	30	6	10	Fejes, I.	7	21	...	...
Balassa, T.	...	...	9	23	Fernald, C. F.	204	390	285	545
Ball, A. R.	15	21	11	18	Flavin, J.	...	...	1	7
Barrera, S.	...	...	3	7	Ford, C. B.	198	206	95	101
Barroso, J. J.	6	6	...	...	Frogel, J. A.	...	...	6	12
Bartha, L.	8	78	6	19	Fuller, K.	79	82	7	7
Bash, D.	10	14	11	18	Garland, G.	...	...	2	2
*Berg, R.	17	17	...	...	Glenn, F. R.	2	2	...	...
Bieda, S. W.	2	10	...	...	Glenn, W. H.	2	2	...	...
Borquez, P.	...	...	5	6	Godfrey, N. B.	17	19	...	...
Brady, R. F.	24	30	28	47	Gonthier, A.	7	10	4	5
Braune, W.	...	...	28	103	Halbach, E. A.	33	33	4	4
Bream, G.	10	10	5	5	Hampton, W. R.	...	...	3	3
Brinley, F. J.	1	2	...	...	Hartmann, F.	161	198	180	204
Buckstaff, R. N.	...	...	30	153	Hicks, R. L.	6	17	5	26
Burt, S. E.	38	86	24	47	Hiett, L.	4	10	7	27
Carbacho, P.	...	...	2	2	Honda, H.	...	...	30	82
Celis S., L.	...	...	6	7	Hull, A.	...	...	2	2
Cobb, J.	...	...	1	1	Hurless, C.	8	13	10	40
Conklin, R.	10	11	12	19	Hutchings, N. O.	15	15	...	...
Cragg, T. A.	369	396	334	347	Judd, D.	7	7	...	...
Czuia, C.	...	...	6	6	Kaminski, W. J.	1	1	...	...
D'Ardillon, M.	...	...	1	1	Kastin, H.	...	...	26	26
de Kock, R. P.	142	694	130	553	†Kelly, F. J.	20	36	16	22
de la Vega, L., R.	...	...	93	324	Knowles, J. H.	8	14	14	33
de la Vega, L., X.	...	...	12	16	Lacchini, G. B.	40	136	24	36

*Plus 25^m AE Aqr.

†plus 20^m AE Aqr.

Observer	Nov. Var.	Nov. Ests.	Dec. Var.	Dec. Ests.	Observer	Nov. Var.	Nov. Ests.	Dec. Var.	Dec. Ests.
Lazo, A.	...	...	2	2	Ramthun, D.	...	...	1	1
Lattey, M.	23	28	...	...	Renner, C. J.	...	...	186	227
Leithoff, D.	6	10	...	...	Ries, J.	2	2	...	...
Lewindon, F.	1	1	...	...	Riquelme, D.	...	...	5	5
Lowder, W. M.	33	75	9	9	Rizzo, P. V.	2	2	8	12
Lucas, D.	5	10	9	14	Robinson, L. J.	55	116	40	209
Marcovites, G.	...	...	1	4	Romano, I.	...	...	1	1
Martinez G., A. E.	...	...	2	43	Rosebrugh, D. W.	15	98	18	87
Matthies, D.	1	1	...	...	Salce M., H.	...	...	6	6
McFarland, T.	48	154	32	74	Schilling, M.	...	...	7	18
McPherson, C. A.	20	20	23	23	Schroder, W.	...	...	1	25
Mende, R.	...	...	10	58	Seavey, H. L.	...	...	7	17
Miller, R. W.	5	5	45	67	Sharpless, A. P.	12	14	24	28
Miller, W. A.	36	54	25	30	Sherwood, D. A.	6	32	7	21
Montague, A. C.	21	24	27	32	*Shinkfield, R. C.	7	17	4	11
Morgan, F. P.	17	38	20	24	Smith, G. W.	3	3	...	...
Mourilhe S., P.	12	19	8	8	Solano, S.	...	...	1	1
Muniz B., L.	3	3	2	2	Specht, H. E. M.	7	7	...	...
Murphy, A. T.	4	7	8	8	Szabo, P.	5	16	...	...
Newton, C.	...	...	4	4	Szekely, C.	7	58	5	57
Nightingale, H. C.	4	13	8	14	Taboada, D.	208	250	261	550
Olmsted, M.	8	11	11	11	Tavares, O. C.	8	9	...	...
Oravec, E. G.	228	564	224	514	Thomas, M. A.	3	26	4	22
Orchiston, D. W.	12	35	...	...	Thompson, J. R.	...	...	1	2
Pearcy, R. E.	1	1	2	2	Travis, N.	2	3	2	8
Pearlmutter, A. E.	...	...	18	18	Tsai, C. H.	...	...	33	61
Peltier, L. C.	32	157	25	144	van Zyl, L. L.	39	88	43	80
Pena V., J.	...	...	1	3	Vodrazka, G.	6	23	3	9
Petik, P.	...	...	3	7	Ward, D.	...	...	1	10
Pinter, S.	5	9	...	...	Wend, R. E.	2	2	...	...
Prat, M.	...	...	1	1	Williamson, L. J. A.	4	4	...	...
Price, R. T.	10	12	10	44	Wilson, C. F.	54	65	3	3
Quester, W.	...	...	5	35	Yamada, T.	60	217	61	299
Quijada, P.	...	...	2	5					

*Plus 1[h] UV Cet.

A.A.V.S.O. Nova Search Report (from George Diedrich, Chairman). Observations of nova search areas were made by the following 19 observers for a total of 366 area-nights reported. Each name is followed by the number of observations made in September and then October, 1960. Mrs. E. E. Bridgen—15, 17; I. P. Debono—4, 6; F. J. DeKinder—15, 24; D. Diedrich—5, 11; G. Diedrich—6, 8; Kenneth Fuller—55, 0; G. Gaherty, Jr.—2, 5; D. Humphrey—20, 0; W. Isherwood, Jr. 23, 20; J. Low—0, 11; H. Nightingale—17, 14; D. W. Orchiston—8, 0; R. Price—1, 0; F. Traynor—8, 12; G. Vodrazka—7, 0; G. Wedge—3, 9; K. A. Wells—12, 15; I. K. Williamson—4, 7; K. Zorgo—0, 2.

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